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STUDIES ON METHODS FOR CONTROL OF POLLINATION IN SUGAR BEETS[1]

E. E. DOWN and C. A. LAVIS[2]

This article reviews experiments conducted at the Michigan Experiment Station[3] to control the pollination in the production of close-fertilized[4] sugar beet (*Beta vulgaris*) seed. Three methods of controlling pollination were studied, *viz.*, space isolation of individual mother beets,[5] enclosing mother beets within cloth cages, and covering individual seed stalks with vegetable parchment paper bags.

Ordinarily, under cultivation, the sugar beet is a biennial plant, producing a fleshy root the first season and a seed crop during the second year of its growth. Artschwager (1)[6] states that, "The mature inflorescence or 'seed bush' is composed of large, paniculate, more or less open, spikes bearing the flowers and later the seeds. The sessil flowers are usually in clusters of two or three which are attached to the inflorescence axis or secondary branches of the latter." The small flowers are perfect, and two or more grow together at the base to form a hard, irregular body called the seed ball. The pollen of an individual flower is normally shed one day before its stigma is exposed. Artschwager (1) says, "For that reason, the individual flower of a cluster is ordinarily not selfed." Shaw (4) has found that flowers of the same plant, located on different stems or branches, are not sterile. The seed produced under normal conditions is the result of close-fertilization or cross-fertilization. The pollen is transferred by wind, thrips (4), and possibly by other insects.

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[1] Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 10 (New Series). Received for publication May 27, 1929.

[2] Research Associate and Assistant, respectively, in Farm Crops, Michigan Agricultural Experiment Station; and Agents, Office of Sugar Plant Investigations, U. S. Dept. of Agriculture.

[3] The sugar beet breeding project is carried on cooperatively by the Farm Crops Section and the Office of Sugar Plants, U. S. Dept. of Agriculture.

[4] The term "close-fertilized" is used to mean that pollen from a flower pollinates the stigma of another flower growing on the same plant, resulting in fertilization.

[5] By the term "mother beet" is meant a root harvested without removing the crown buds, stored through the winter, and planted out for seed production the second year.

[6] Reference by number is to "Literature Cited," p. 9.

SPACE ISOLATIONS

Reed (3) reports little success with space-isolated beets grown in the vicinity of Blissfield, Michigan, except when the apical buds were removed from the main stalk to increase the production of lateral stems. In his tests, seed production was further stimulated when these plants were loosely hooded with large paper flour sacks.

Space-isolation of mother beets (Fig. 1) was started at this station in 1923, when 538 beets were isolated in farm gardens in the vicinity of Lansing, Michigan. Individual plantings were separated by a space of at least one-half mile, a distance believed, under Michigan conditions, practically to eliminate a possibility of pollen being exchanged from one plant to another Because of the destruction of many seed plants by live stock or other unavoidable causes, many of these plantings were lost. Being planted in the country, the seed plants had very little protection from the wind, which may have blown away a major part of the pollen as it was produced.

FIG. 1.—Mother beet 26081, isolated from its nearest neighbor by a space of one mile, produced 55 grams of seed which germinated 3%.

Because of these considerations, planting in farm gardens was discontinued after this one year, and since then, all isolations have been made in city gardens. The practice followed is to plant only one beet to a city block in the older and more fully developed sections of the city. Such plantings have always been made on the east side of the north and south streets, thus giving the flowering plants more or less protection from the prevailing westerly winds. Further to guard against the possibility of wind transfer of pollen between these isolated beets, the plantings in successive blocks are staggered as follows: If a beet is planted in the even-numbered block on any given street, the next planting is made in the odd-numbered block on the next street east or west.

The city garden seems better suited to isolated plantings of this type than a farm garden. The city gardens, as a rule, are prepared earlier and receive better care than the average garden found on the farm. City gardeners have, as a rule, taken a keen interest in the growth and care of the isolations, often protecting and watering them.

However, many city gardens are not plowed in the fall and Swiss chard (*Beta vulgaris cycla*), living over after a mild winter, is left in the garden as a source of greens. During the second year of its growth, Swiss chard, like sugar beets, sends up seed stalks which flower at the same time as sugar beets, and cross-fertilization often takes place. Fortunately, chard usually freezes out in this locality, as the winters are quite severe. Retired farmers, living in town, very often save a few red garden beets over winter to produce their own stock of seed. These plantings are a further source of foreign pollen The characteristic pale lettuce-green color of the Swiss chard leaves, and the red coloring of the table beet are dominant to the green leaves and white roots of the sugar beet, making the F_1 of these crosses readily distinguishable in the seedling stage

A review of the results obtained with space-isolated individual seed beets during the years 1923 to 1927, inclusive, is given in Table 1

TABLE 1.—*Results obtained with space-isolated seed beets, 1923–27.*

Year	Space isolated	Died	Destroyed	Number of beets Not producing seed stalks	With seed stalks Without seed	With seed stalks With seed
1923	538	49*	53	74	124	238
1924	532	13	31	10	15	463
1925	322	4	28	12	9	269
1926	164	59†	5	5	11	84
1927	152	27	6	7	10	102

*Beets selected for mothers in 1922 were stored in outdoor pits during the winter of 1922–23.

†The beets isolated in 1926 were frozen slightly in the ground before harvest in the fall of 1925.

An interesting fact in this table is that 124 out of 538 beets isolated in 1923 sent up seed stalks but failed to produce seed. As very few of them were protected from the wind, it seems logical to conclude that all of the pollen produced by these plants was completely blown away. No doubt the wind also influenced the amount of seed produced on many of the others showing low productivity.

Because the results for space isolations are very similar for all the years, only the results for one year are given in detail. Seed from 269 isolated mother beets for 1925 is classified as follows:

- Ninety isolations produced only a few seeds to 5 grams each.
  - 56 of which germinated 0%
  - 14 of which germinated 1– 5%, 1 showing 10% x Red
    - 1 showing 1% x Chard
  - 11 of which germinated 6–10%, 1 showing 8% x Red
    - 1 showing 3% x Chard
  - 4 of which germinated 11–25%, 1 showing 10% x Red
  - 4 of which germinated 26–50%
  - 1 of which germinated 51–75%
- Fifty-four isolations produced 5.1 grams to 10.0 grams each
  - 25 of which germinated 1– 5%, 1 showing 20% x Red
    - 1 showing 15% x Red
    - 1 showing 8% x Red
    - 1 showing 4% x Red
  - 11 of which germinated 6–10 %, 1 showing 8% x Red
  - 8 of which germinated 11–25%
  - 6 of which germinated 26–50%
  - 4 of which germinated 51 75%
- One hundred eight isolations produced 10 grams to 50.0 grams each.
  - 12 of which germinated 0%
  - 50 of which germinated 1– 5%, 1 showing 81% x Red
    - 1 showing 30% x Red
    - 2 showing 8% x Red
    - 1 showing 6% x Red
    - 1 showing 4% x Red
  - 19 of which germinated 6–10%, 1 showing 20% x Red
    - 1 showing 14% x Red
  - 12 of which germinated 11–25%, 1 showing 50% x Red
    - 1 showing 5% x Red
  - 10 of which germinated 26–50%
  - 4 of which germinated 51–75%
  - 1 of which germinated 78%
- Fourteen isolations produced 50.1 grams to 100 grams each.
  - 4 of which germinated 0%
  - 4 of which germinated 1– 5%
  - 4 of which germinated 6–10%
  - 1 of which germinated 11–25%
  - 1 of which germinated 26–50%
- Two isolations produced over 100 grams each.
  - 1 of which germinated 6–10%
  - 1 of which germinated 51–75%

It will be noted that seed production varied from only a few seeds to over 100 grams per plant, however, the great majority produced less than 50 grams each. In fact, 94% of the mother beets planted in 1925 produced from a few seeds to 50 grams per beet. The germination of the seed of 166 out of the 269 of these was 5% or less. Seventy-two lots of seed did not germinate at all. Seed failing to germinate was not limited to low producers, however, since four isolations yielded over 50 grams of seed which failed to germinate Red garden beet and Swiss chard hybrids appeared in the offspring from 20 isolated mother beets. High viability of seed produced on a space-isolated beet is not a safe index of cross-fertilization with red garden beets or Swiss chard as none of the isolations with seed germinating over 25% showed any such mixture

The occurrence of considerable garden beet and Swiss chard hybrids in the offspring of isolated mother beets makes it necessary to consider the likelihood of some of the seeds actually produced on the space-isolated mothers being the result of crossing between neighboring mothers. There are two reasons for believing that no crossing of this type took place. First, it would seem that the distance between mothers isolated in farm gardens in 1923 practically eliminated any possibility for pollen transfer Since 1923, the plantings have been considerably closer to each other, but the presence of many houses, trees, bushes, etc., gave each isolated mother beet ample protection from its nearest neighbor. Second, and most important, the appearance of the offspring, grown under field conditions, indicates that the normal segregation of characters expected under close fertilization is taking place.

Attention has been called to the comparatively large number of isolations that failed to produce viable seed. On some individual isolations, the seed balls formed were hardly more than the rudiments of the flower, while others formed apparently normal seed balls that had every external appearance of containing two or three seeds, but these, like the undeveloped type, did not germinate. Internal examination of these apparently normal seed balls showed that for some unknown reason the fruit (seed balls) developed without the production of any seed. It may be that pollination (the actual presence of pollen on the stigma) had stimulated the fruit (seed ball) to develop, while fertilization (union of gametes) did not take place to form an embryo.

CAGING EXPERIMENT

Vilmorin (6) reports the production of sugar beet seed on mother beets isolated within cloth cages, whenever the isolated beets flowered before the heat of July. Roots are planted a few feet apart, as early as March 1, and covered to protect from frost, if necessary, or they are planted in the greenhouse and transplanted to the field after danger of frost is past. The cloth cage, consisting of a bag held out from the plant by hoops, is set over the beet before flowering begins. During the flowering period the cage is shaken daily to insure pollination Similarly, it is a general practice of some commercial European seed firms, producing sugar beet seed, to isolate adjacent mother beets within cloth cages. However, evidence has not been given to prove that seed produced within these cages is due to close-fertilization and not to cross-fertilization between adjacent isolations

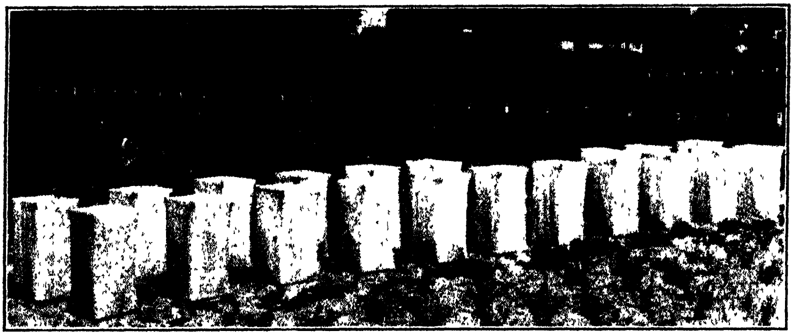

FIG. 2.—Cloth cages covering adjacent sugar beet and red garden beet seed plants for the study of close fertilization.

It is evident that the success of any such practice will depend upon the efficiency of the screening action of the cloth cage. In order to determine if cloth cages will prevent cross-pollination between adjacent mother beets under Michigan conditions, red garden and sugar beets were planted alternately at 6-foot intervals for seed production. Wooden frames were built around each beet and carefully covered with a fine-meshed cloth (Fig. 2) which goes under the trade name of Lonsdale nainsook. Nainsook was chosen after carefully studying the mesh of many closely woven types of cloth. The entrance of thrips at the seams was prevented by double folding the cloth, and at the base by banking with soil.

The opinion of the entomologists at this station is that this cloth, being so closely woven, affords very little chance for thrips to pass directly through it. The red garden beets normally produce pollen simultaneously with the sugar beets and the F_1 progeny resulting from the red pollen on sugar beet flowers could be detected by the color in the seedling. The results obtained in these experiments being very similar for the different years, only the data for the year 1925 are given in detail in Table 2.

TABLE 2.—*Results of caging experiments with seed beets at Lansing, Mich., 1925.*

Beet No.	Amount of seed in grams	Total germination	Total seed planted showing red seedlings
		%	%
1	36	42	32
2	8	68	32
3	14	28	8
4	43	34	3
5	63	8	8
6	10	22	1
7	29	42	16
8	50	44	18
Average	31.6	36.0	14.8

The average amount of seed produced per caged beet was 31.6 grams, with an average germination of 36%. The average number of red seedlings, which were unmistakably garden beet hybrids, was 14.8 per 100 seeds planted or 41% of the total number of seed balls which germinated Assuming that an equal amount of crossing took place between adjacent sugar beets as did between adjacent red beets and sugar beets, then 82% of the total seed germinating were crosses

Before repeating this caging experiment, photomicrographs of different types of cloth were taken and the tightest woven cloths chosen for use in 1926. A very closely woven cloth obtained from France[7] and thought to be the same as that used by Vilmorin (6) was included in the test However, the crossing results obtained in 1926 were similar to those of the previous year The method of transferring the pollen from the caged garden beets to the caged sugar beets is not known. These results indicate that such cloth cages cannot be used under Michigan conditions to secure adequate isolation of individual mother beets.

ISOLATION WITHIN PAPER BAGS

Nilsson (2) reports the successful use of parchment paper bags in the production of close-fertilized sugar beet seed at Svalof, Sweden. He was most successful when branches from two adjacent plants, judged by him to be identical, were placed within the same sack.

[7] Obtained by Dr. G. H. Coons, Principal Pathologist, Office of Sugar Plant Investigations, U. S. Dept. of Agriculture, from Dr. Jacques Leveque de Vilmorin.

Movement of thrips between sacks was prevented as explained later. Stewart and Tingey (5) report the successful production of sugar beet seed within the 2-pound, grocery, paper bags at Logan, Utah. Their method of attaching the sack to the seed stalk did not necessarily prevent the movement of thrips from exposed to covered flowers.

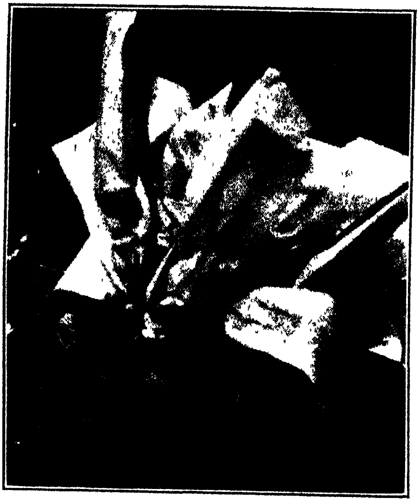

FIG. 3.– A mother beet with several seed stalks covered with vegetable parchment paper bags. The seams of these bags were water-proofed with enamel oil before exposure to weather.

Vegetable parchment paper bags were used at this station in 1927 to cover individual seed stalks. Eight to 10 sacks per plant (Fig. 3) were placed on some 30 plants As explained by Nilsson (2), thrips or other insects were prevented from carrying pollen of exposed flowers to covered flowers as follows; Cotton batting was tied about the seed stalk, and the mouth of the sack (after wetting in water) tied firmly over the cotton (Fig. 4). Parchment sacks thus treated shrink and make very tight junctions with the cotton to prevent the entrance of any thrips to the covered flowers. The covered part remained green within the sacks and appeared to be developing normally until a sudden rise in the temperature for a few days seemed to cause blasting of every flower. No seed was obtained from any bagged branch.

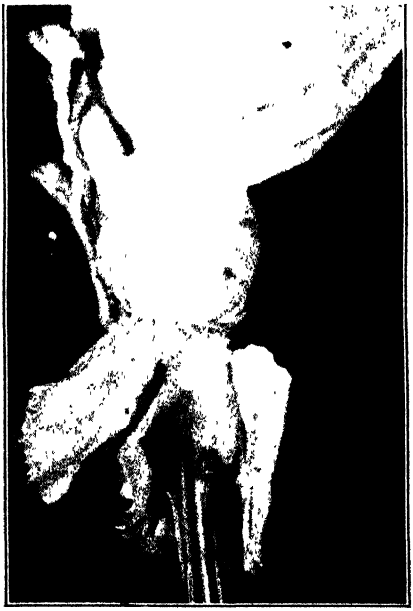

FIG. 4.—Manner of attaching parchment bags to seed stalks. Note cotton batting and heavy cotton twine.

CONCLUSIONS

1 Close-fertilized sugar beet seed can be produced under Michigan conditions by the space isolation of mother beets. Well-sheltered city gardens are very suitable for this purpose, but care must be taken to destroy nearby seed plants of Swiss chard and red garden beets. Such random crosses of this type as may occur are readily recognized in the F_1 generation and do not prevent further work with the pure sugar beet material.

2. Other workers report successful production of close-fertilized sugar beet seed from roots planted in close proximity, isolation being obtained by use of cloth cages. Experiments with similar cages at this station, in which red garden mother beets were used alternately with sugar beets, gave 31.6 grams of seed per caged sugar beet Forty-one per cent of the viable seed was identified as hybrid. Assuming the same amount of crossing between sugar beets as between garden beets and sugar beets, then 82% of the viable seed would be the result of cross-fertilization

3. Successful production of close-fertilized sugar beet seed within parchment paper bags has also been reported. This method was tried at the Michigan Station in 1927, but no seed was produced on bagged seed stalks. The lack of success may possibly be attributed to extremely high temperatures which prevailed during the flowering period. Further trials are necessary before conclusions can be drawn concerning the possibilities of success with this method, but our experience indicates that total failures to set seed may occur under certain climatic conditions.

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FURTHER EVIDENCE CONCERNING THE SIGNIFICANCE OF NITROGEN IN SOIL ORGANIC MATTER RELATIONSHIPS[1]

F. J. SIEVERS[2]

In bulletin 212 of the Massachusetts Agricultural Experiment Station (1),[3] there appears a history of fertility plats ("North Soil Test"), together with a very complete record of treatment and results from soil fertility tests that had been in progress since 1890

The original plan included 12 plats, but a thirteenth was added in 1902 to satisfy an interest in the effect of nitrogen when applied in an organic form instead of in the form of nitrate of soda. All plats, with the exception of the checks, received different treatments, and the fertilizer applications indicated in Table 1 have been made annually up to the present date, covering a period of 39 years, with the exception that for two years during this period no fertilizer was applied and that for eight years the application was doubled

TABLE 1.—*The North soil test of the Massachusetts Agricultural Experiment Station.*

Plat No.	Treatment	Pounds per acre
1	No fertilizer	—
2	Nitrate of soda	160
3	Dissolved boneblack*	320
4	No fertilizer	—
5	Muriate of potash	160
6	Nitrate of soda	160
	Dissolved boneblack*	320
7	Nitrate of soda	160
	Muriate of potash	160
8	No fertilizer	—
9	Dissolved boneblack*	320
	Muriate of potash	160
10	Nitrate of soda	160
	Dissolved boneblack*	320
	Muriate of potash	160
11	Plaster†	800
12	No fertilizer	—
13	Nitrate of soda	160
	Dissolved boneblack*	320
	Muriate of potash	160
	Organic nitrogen	160

*Beginning with 1922, superphosphate was substituted for dissolved boneblack.
†1892–95, 160 pounds per acre; 1896, increased to 400 pounds per acre; 1902, increased to 800 pounds per acre.

Over the period of 1899 to 1916 the west half of each plat was limed at a rate which in four applications totaled 4½ tons per acre.

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[1] Contribution No. 100, Massachusetts Agricultural Experiment Station, Amherst, Mass. Received for publication May 28, 1929.

[2] Director.

[3] Reference by number is to "Literature Cited," p. 13.

During the 39 years from 1890 to 1928, inclusive, the following crops were grown, each for the number of years indicated: Grass and clover, 8; orchard, 7; soybeans, 5; onions, 4; corn, 3; potatoes, 3; rye, 3; cabbage, 2; beans, 1; oats, 1; turnips, 1; and millet, 1. The orchard was planted in 1922 and has occupied the plats for the last seven years. During this period the soil has been clean cultivated up to the latter part of July, then seeded to either oats or buckwheat which were harrowed into the soil for green manure the next spring.

The soil on these plats is classified as a Merrimac coarse sandy loam, containing percentages of soil separates as follows: Gravel 0.42, coarse sand 1.19, medium sand 1.34, fine sand 7.21, very fine sand 61.83, silt 24.43, and clay 3.58 This mechanical composition of the soil, supplemented with management experience, makes evident its splendid adaptability to crops requiring intensive tillage Since it is quite generally accepted that organic matter has a beneficial influence on tilth, and because good tilth is so very essential to intensive agriculture, there is a pronounced interest in maintaining a high percentage of organic matter Various specific practices and treatments are considered effective in accomplishing this and are very generally followed, even though they may be supported by very little investigational evidence.

While at the Washington Agricultural Experiment Station, the writer, in joint authorship with Holtz (2, 3, 4, 5), expressed the following conclusions concerning the possibilities of increasing or maintaining soil organic matter. That the nitrogen-carbon ratio of soils at about 11.5 is practically a constant That, so far as effective soil organic matter is concerned, the organic carbon cannot be increased without proportionately increasing the organic nitrogen; or that soil organic matter can be increased or maintained only in the proportion that the organic nitrogen is increased or maintained. That, since an increase in soil nitrogen if at all possible is at best very slow, it must naturally be equally difficult to increase the soil organic nitrogen; and that this is borne out by attempts to measure such increases. That those soil management practices which prove most effective in permanently maintaining crop yields are also the ones that have the greatest influence on the maintenance of soil organic matter.

Since these conclusions were based on results obtained under soil and climatic conditions of the Pacific Northwest, it was naturally of interest to know whether they could be supported on evidence available in New England where these natural conditions are different and where there was an opportunity to obtain data based on 20 different treatments applied more or less regularly over a 39-year period.

For this purpose representative samples of soil were taken from both the limed and unlimed portions of each plat in the "North Soil Test." Each of these samples was the composite of 10 individual samples taken at a depth of 6 inches. These samples were analyzed for nitrogen, organic carbon, carbon as carbonates, and organic and volatile matter. The results are given in Table 2.

TABLE 2.—*Influence of liming and of various fertilizer treatments on the organic carbon and nitrogen content of soils, "North Soil Test", after 39 years.**

Plat No.	N-C ratio	Organic and volatile matter %	Nitrogen %	Organic carbon %	Carbon as carbnoates %
			Unlimed		
1	12.25	3.889	0.1173	1.437	0.0060
2	10.29	3.181	0.1207	1.242	0.0060
3	12.51	3.884	0.1176	1.471	0.0060
4	12.81	3.885	0.1116	1.430	0.0060
5	10.19	2.404	0.0951	0.969	0.0046
6	11.13	3.055	0.1047	1.165	0.0044
7	13.42	3.660	0.1033	1.386	0.0039
8	12.81	3.010	0.0887	1.136	0.0036
9	12.87	3.159	0.0863	1.111	0.0048
10	13.35	3.780	0.0988	1.319	0.0042
11	14.02	3.680	0.0892	1.251	0.0048
12	13.94	3.814	0.0938	1.308	0.0048
13	11.53	3.674	0.1223	1.410	0.0036
Average	12.39	3.467	0.1038	1.279	0.0048
			Limed		
1	14.08	3.317	0.0905	1.274	0.0053
2	13.47	3.517	0.1035	1.394	0.0053
3	12.85	3.485	0.1044	1.342	0.0053
4	11.54	3.362	0.1129	1.303	0.0036
5	11.78	3.771	0.1279	1.507	0.0060
6	10.52	2.788	0.1123	1.181	0.0048
7	13.81	4.139	0.1145	1.581	0.0036
8	13.53	4.019	0.1176	1.591	0.0038
9	12.94	3.259	0.1168	1.511	0.0038
10	12.93	3.919	0.1261	1.630	0.0038
11	10.15	2.806	0.1163	1.180	0.0048
12	11.32	3.680	0.1253	1.418	0.0048
13	11.47	3.804	0.1296	1.486	0.0048
Average	12.34	3.528	0.1152	1.414	0.0046

*Analyses were made by Professor Henri D. Haskins of the Fertilizer Control Laboratory, Massachusetts Agricultural Experiment Station.

These analyses seem to indicate: That the nitrogen-carbon ratio of soils is fairly constant. That the nitrogen-carbon ratio of this soil is somewhat wider than for soils in the Pacific Northwest; especially where precipitation is limited. That pronounced variations in soil treatments, even though effective in producing wide differences in yield, had apparently no consistent influence on soil organic matter nor on the nitrogen or carbon content of the soil.

That liming, although it produced regular increases in yield, had apparently little influence on soil organic matter content. That whatever slight increase liming may have produced in soil organic matter, this increase was so directly proportional to the increase in nitrogen and carbon that the ratio between those two elements remained unchanged. That the former conclusion, that there can be no apparent increase in soil organic matter without a proportionate increase in nitrogen, is apparently well founded.

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LIME-MAGNESIA RATIOS IN DOLOMITIC LIMESTONES AS INFLUENCING SOLUTION AND SOIL REACTIONS[1]

W. H. MacIntire and W. M. Shaw[2]

The Great Appalachian Valley is seamed with alternate streaks of high-calcic and dolomitic limestones. The relative values of these two types of stone and the reactions induced by them in the soil are therefore of special interest in this region.

When limestones and dolomites of comparable neutralizing values are subjected to solubility tests, the high-calcic rocks dissolve more readily in the several mineral and organic acids. In the practice of liming, this difference in speed of disintegration apparently has no economic significance for general rotations, since finely ground incorporations of both types of rock are readily disintegrated by those soils that have sufficient fixing power But the soil that has absorbed limestone is a system different from the one that was derived from soil plus dolomite.

For many years there existed some uncertainty as to the value of the high-magnesic and dolomitic limestones and even a prejudice against their use for soil liming. Magnesium was considered a substance that should be used with caution, if at all. This attitude was probably due to the conclusions that had been drawn from some of the many lime-magnesia ratio studies that followed the promulgation of Loew's hypothesis (8).[3] In most of these studies, pot cultures in particular, magnesium was added by means of the hydrated precipitated carbonate. This material has characteristic properties that are entirely different from those possessed by the magnesium carbonate of the natural high-magnesic rocks The soil reactions induced by ground dolomitic limestone cannot be determined by means of analogies that are based upon the substitution of equivalent amounts of calcium and magnesium added in caustic forms, or as precipitated carbonates.

Agronomic studies at the Tennessee Station have shown (17) that dolomitic limestones and high-calcic rocks have equal value for general rotations. The 15-year studies of the New Jersey Station (7) also indicate full equality, and in some instances superiority, for the dolomitic materials.

The results of Garner (4) and those of Moss (18) showed that dolomitic limestone may be used to insure adequate quantities of

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[1] Contribution from the Department of Chemistry, University of Tennessee, Knoxville, Tenn. Received for publication May 28, 1929.

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[3] Reference by number is to "Literature Cited," p. 26.

magnesium for such magnesia-loving crops as tobacco. On the other hand, the high-calcic materials may depress the solubility of the magnesia content of the soil (10, 13, 14) and thus prove harmful to such crops as tobacco. Conversely, magnesia additions may exert an even more marked reciprocal effect upon the solubility of the soil's supply of calcium (10, 13, 14). The two types of limestone do possess one common property in that both repress the solubility of the soil's supplies of native potassium (15, 16).

The physical properties, as well as the solubilities, of dolomites are influenced to a marked degree by their calcium-magnesium ratios and the extent of impurities This is especially true in the correlation between hardness and silica content. Primarily on the basis of resistance to different dilute organic and mineral acids, Bottini (1) has divided the limestones into three groups, *viz.*, marly, concretionary, sandy, and fossiliferous types; argillaceous types; and dolomitic, saccharoid, and compact types He also correlates such resistance with geological age and states further that, " . . . not only should the content in $CaCO_3$ be taken into account, but also its behavior toward decomposition, which varies according to the nature of the soil itself."

OBJECTIVES

Certain observations (2) had been made concerning variations in the solubilities of dolomites, and the proportions of calcium and magnesium carried by their solutions in carbonated water The proportions of calcium and magnesium imparted to the percolates from a dolomite-treated soil had also been determined (4, p 452). These earlier findings suggested the desirability of ascertaining the influence that calcium-magnesium ratios and purity exert upon (a) the speed of the disintegration of dolomites, (b) the initial and ultimate compositions of their carbonated water-solutions, (c) the resistance that the absorbed calcium and magnesium offer to natural hydrolytic agencies, and (d) the order in which the calcium and magnesium bicarbonates of a dolomite solution react with acids.

EXPERIMENTAL

The extractions of the dolomites by carbonated water were all made at room temperature and atmospheric pressure. The solubilities in carbonated water are, of course, influenced by temperature and pressure. The working temperature of the present studies may be taken as being an approximation to that which prevails during the period when CO_2 is generated most extensively in the soil, whereas Bouyoucos and McCool (3) have shown that the pressure of a soil's atmosphere may be considered as identical with hat of the adjacent aerial atmosphere. Hence, the recorded behavior of the carbonated-water systems may be considered as analogous to the activities induced by the CO_2 content of the soil solution.

COMPOSITION OF DOLOMITES AND THEIR SINGLE CARBONATED-WATER EXTRACTS

Ten dolomites were used for single extractions. Their calcium-magnesium contents and titration values, in terms of $CaCO_3$ equivalence, are given in Table 1. The solubilities registered by 20-gram charges of 100-mesh fineness in 2,000 cc of carbonated water, after a 5-day equilibrium period at room temperature (± 25° C) and atmospheric pressure, and their proportions of calcium to magnesium yielded to *single* carbonated-water extracts, together with the calcium-magnesium ratios in the original rock, are given in Table 2.

TABLE 1.—*Partial analyses of 10 dolomitic limestones.*

Rock No.	Insoluble matter %	R_2O_3 %	$CaCO_3$ equivalences of Calcium content %	Magnesium content %	Ca+Mg content %	Titration values %
1	0.28	0.40	53.22	53.97	107.2	107.3
2	0.72	0.44	53.08	53.74	106.8	106.8
3	2.74	0.80	51.88	52.62	104.5	103.8
4	9.70	0.80	49.04	47.29	96.3	95.3
5	7.99	0.93	52.17	47.38	99.55	97.3
6	9.24	1.10	50.16	45.08	95.2	93.3
7	2.42	1.10	55.52	47.56	103.1	102.5
8	21.40	2.50	43.50	37.00	80.5	77.8
9	4.00	0.80	55.14	46.25	101.4	101.3
10	25.04	3.08	51.82	21.55	73.4	73.0

TABLE 2.—*Solubilties of ten dolomitic limestones in carbonated water, 20-gram charges in 2,000 cc of distilled water.*

Rock No.	Alkalinity, Ml N/10 per 100 of solution	$CaCO_3$ equivalences per liter of solutions Calcium content, grams	Magnesium content, grams	Ca+Mg content, grams	Ca:Mg ratio in carbonated water solution	Ca:Mg ratio in rock
1	7.4	0.205	0.200	0.40	1.02:1	0.99:1
2	5.6	0.158	0.148	0.31	1.06:1	0.99:1
3	8.4	0.244	0.219	0.46	1.10:1	0.99:1
4	7.2	0.196	0.166	0.36	1.18:1	1.03:1
5	9.6	0.359	0.126	0.48	2.80:1	1.11:1
6	12.0	0.478	0.155	0.63	3.08:1	1.11:1
7	10.8	0.452	0.112	0.56	4.00:1	1.17:1
8	9.8	0.327	0.193	0.52	1.69:1	1.18:1
9	12.2	0.545	0.090	0.63	6.05:1	1.19:1
10	16.0	0.791	0.051	0.84	15.50:1	2.40:1

The rocks were found to range between 0.99:1 and 2.40:1 in their calcium-magnesium ratios. The analyses and titration values show (a) that 5 of the 10 rocks have a $CaCO_3$ equivalence in excess of

100%, (b) that 3 have a value approximating 95%, (c) that 2 have a value close to 75%, and (d) that 2 have insoluble-R_2O_3 contents above 23%. One of the latter, No. 10, has the highest proportion of calcium carbonate and gives the maximum solubility found, whereas the solubility of the other, No 8, is greater than that of either of the purer rocks, Nos. 1, 2, 3, 4, and 5. The calcium-magnesium ratio of the low-grade rock, No. 10, was more than twice that of any one of the other nine, and its corresponding ratio in the carbonated water solution is the maximum obtained, 15 5 to 1. If the generally accepted figure of 30% of magnesium carbonate is used to classify a rock as a dolomite, rock No. 10 cannot be designated as a true dolomite.

The calcium-magnesium ratios of four of the nine true dolomites, Nos 1, 2, 3, and 4, are practically 1.1, and the several composition ratios do not vary greatly from those found in their respective carbonated-water solutions. On the other hand, the proportions of calcium found in rocks Nos. 5, 6, 7, 8, and 9 are decidedly less than those found for their respective solutions in carbonated water. Three rocks of the first group and two of the second group have $CaCO_3$ equivalences in excess of 100%. But the ratios found in the carbonated-water extracts of the highest purity rocks of the first group differ materially from those found in the same type of rock in the second group It is evident that the two groups are inherently different It is also evident that the rocks that carry the higher proportions of calcium are dissolved more rapidly than are those with Ca Mg ratios approaching 1 1

From the foregoing data it is evident that the initial disintegration of a specific dolomite is one factor that affects the early proportions of calcium and magnesium that will become available for reactions in the soil system and for removal by growing plants It is obvious that, with a calcium-magnesium ratio of 1.1 in the rock and a 2.1 ratio or greater in its carbonated-water extract, the ratio of the residual $CaCO_3$ to the residual $MgCO_3$ would be altered. And, were the solution ratio of 2 1 to continue, the residual $MgCO_3$ would soon exceed the residual $CaCO_3$ Such an excess of residual magnesium carbonate would shift equilibria and produce values different from those found in the early carbonated-water extracts. This would follow if calcium and magnesium were dissolved in the same proportions as those that occur in the rock and their subsequent proportions altered by a progressive salting-out of the magnesium from the solution, and likewise if the dissolving of $CaCO_3$ from the $CaCO_3$ $MgCO_3$ solid were selective.

CONSTANCY OF CARBONATED-WATER EXTRACTS

This raises the question as to the constancy of the ratio of calcium to magnesium in successive carbonated-water extracts. This point was studied by subjecting two dolomites, Nos. 5 and 9, to the following procedure. A 1-gram charge was placed in a 200-cc cylinder with 150 cc of distilled water into which was injected a continuous current of cylinder CO_2 for two days, when equilibrium had been attained. The suspension was quickly filtered and the residue returned to the cylinder and again extracted. The results of the seven successive 2-day extractions are given in Table 3. These data indicate that at first there occurred simultaneous extractions of the solid phases, $CaCO_3$ and $CaCO_3$-$MgCO_3$, thus giving a preponderance of calcium in the early extractions. It appeared that the returned residues had soon become depleted of the $CaCO_3$ content that was in excess of that requisite for a 1:1 ratio of calcium to magnesium and that the residue was mainly, if not entirely, the double carbonate $CaCO_3$-$MgCO_3$, since the final carbonated water extracts contained calcium and magnesium in equivalent amounts

TABLE 3.—*The calcium-magnesium ratios found in successive carbonated water extracts of two dolomites at 25°C and atmospheric pressure.*

Extraction No.	Ca-Mg ratio found in carbonated water extracts	
	Rock No. 9*	Rock No 5*
1	5.8:1	2.9.1
2	3.4:1	1.8:1
3	2.0:1	1.5.1
4	1.6:1	1.4:1
5	1 :1	1 :1
6	1 :1	1 1
7	1 :1	1 :1

*No. 9, Tables 1 and 2—Ca-Mg ratio in rock 1.19·1.
No. 5, Tables 1 and 2—Ca-Mg ratio in rock 1.11:1.

The total quantities of calcium and magnesium removed by the seven successive extractions of the two dolomites were determined In each case the excess of dissolved $CaCO_3$ over dissolved $MgCO_3$ was equal to the difference between the determined rock content of $CaCO_3$ and the smaller quantity required to compute an occurrence of calcium equivalent to that of magnesium. In each case the last three residues of the rocks that had been extracted with carbonated water, therefore, contained equivalent quantities of calcium and magnesium. The excess of $CaCO_3$ over that necessary to show an equivalent content of $CaCO_3$ and $MgCO_3$ thus influences the speed by which the $CaCO_3$-$MgCO_3$ enters the carbonated water in the ultimate ratio of 1:1. This excess likewise affects the progressive proportions of calcium to magnesium that are dissolved by the same process in the soil system and thus made available (a) for absorption by the soil, (b) for enrichment of leachates, and (c) for assimilation by plants.

An excess of calcium carbonate is not always the sole factor that tends to give a solubility ratio in excess of 1:1 In some dolomites a part of the magnesium content is present as silicate, for computations often show that the carbonate radical is insufficient to care for either the total calcium-magnesium or for the titration values.

INFLUENCE OF AN EXCESS OF ONE COMPONENT

The foregoing condition—the presence of a mixture of the solid phases, $CaCO_3$ and dolomite—was imposed to a greater degree by the addition of 10 grams of "C. P." $CaCO_3$ to a carbonated-water suspension of 20 grams of dolomite No 3. The results for mixture 2 of Table 4 show that, in this system, there occurred a salting out of the $MgCO_3$ that had been in the dolomite solution and that the solubility of the solid-phase dolomite was depressed; whereas, the $CaCO_3$-equivalent titer of the solution, and its calcium content also, was more than doubled. This produced a system similar to that obtained in a carbonated-water suspension of rock No. 10

TABLE 4.—*The effects exerted by $CaCO_3$ and by $MgCO_3$ upon the solubility of a dolomite in carbonated water.*

Mixture No	Composition of mixture			Titration values		$CaCO_3$ equivalence per L	
	Dolomite,* grams	$CaCO_3$,† grams	$MgCO_3$,‡ grams	N/10 per 100 Ml, Ml	$CaCO_3$ =o= per L, grams	Calcium, grams	Magnesium, grams
1	20	none	none	8.4	0.42	0.244	0.219
2	10	10	none	17.6	0.88	0.856	0.000
3	10	none	10§	103.0	5.15	0.055	5.095
4	10	none	30	246.0	12.30	0.013	12.287

*Rock No. 3, Tables 1 and 2.
†C. P.
‡Hydrated C. P.
§Charge completely dissolved.

Conversely, the addition of 10 grams of precipitated $MgCO_3$, all of which went into solution, brought about a decided increase in titer, and a marked diminution in the $CaCO_3$ content of the dolomite solution. When an addition of 30 grams of precipitated $MgCO_3$ was added to insure an excess of the solid phase $MgCO_3$, there occurred a further rise in titer and an almost complete salting out of the $CaCO_3$ that had been in the original solution of the dolomitic rock. These findings are in harmony with the carbonated-water solution studies with calcium and magnesium carbonates, as reported by Leather and Sen (6).

The effect exerted by $Mg(HCO_3)_2$ upon the solubility of $CaCO_3$ was studied further by the use of a 20-gram constant of solid $CaCO_3$ with seven different amounts of $MgCO_3$ that had been dissolved in carbonated water. The results of Table 5 show the effects that were produced. In the case of systems 2 and 3, the titration values were increased approximately 5% and 10%, respectively, with corresponding $CaCO_3$ solute decreases of 18% and 33%. Beginning with system 4, the preponderance was shifted from calcium to magnesium content, with nugatory calcium values for the systems 6, 7, and 8. Previous analyses of "C. P." magnesic materials had demonstrated (15) that the occurrence of meagre quantities of calcium can not be determined, even approximately, in the presence of large quantities of magnesium by the use of the conventional oxalate method; hence, the last four calcium values were secured by means of the Stolberg method as given by Hillebrand (5).

TABLE 5.—*The effects that varying concentrations of $Mg(HCO_3)_2$ exert upon the solubilities of $CaCO_3$ in carbonated water.*

System No.	Composition of systems		Tirtation values after equilibrium— 5 days contact		$CaCO_3$ equivalence found per L	
	Solid $CaCO_3$, grams	$MgCO_3$ in solution, grams*	N/10 per 100 Ml, Ml	$CaCO_3$ =o= grams	Calcium, grams	Magnesium, grams
1	20	0.000	20.2	1.010	1.005	0.005
2	20	0.438	21.2	1.060	0.820	0.240
3	20	0.875	22.3	1.115	0.672	0.443
4	20	1.750	26.8	1.340	0.452	0.888
5	20	3.500	40.5	2.025	0.220	1.805
6	20	7.000	73.2	3.660	0.066†	3.594
7	20	14.000	129.2	6.460	0.026†	6.434
8	20	30.000	247.0	12.350	0.012†	12.338
9	0	30.000	276.0	13.800	0.008†	13.792

*Keasby and Mattison hydrated $MgCO_3$, U. S. P., having a titration value equal to 100% $CaCO_3$ equivalence.

†Ca determined by the modified Stolberg method, U. S. Geol. Survey Bul. 700 p. 143.

SOIL-DOLOMITE REACTIONS

LYSIMETER FINDINGS

The calcium-magnesium ratio in the carbonated-water solution of a given dolomite is not, however, an index to the calcium-magnesium ratio that may be found in the soil solution, after the dolomite has been absorbed. It would be expected that the addition of a dolomite would increase the occurrence of both calcium and magnesium in the soil's solution, as measured by the composition of rainwater percolates from a fallow soil. This does not necessarily follow. Rock No. 5 was reduced to a fineness of 100 mesh and mixed throughout the full 8-inch depth of a loam and in such quantity as to insure that within one year it would be completely absorbed or "fixed" by the soil—an equivalence of 1 ton of CaO, or 3,570 pounds of $CaCO_3$. The amount of calcium removed by the rainwater leachings from this soil-dolomite mixture over a period of 5 years was less than that from the untreated soil (14, p. 452). The rainwaters usually contain more calcium than magnesium, but this relationship is considered as being taken care of by the controls. The calcium-magnesium ratio in the rainwater leachings from the controls of this soil was 2.28:1 (14, p. 450), whereas the corresponding ratio found in the percolates from the soil plus the dolomite addition was only 1:1.

When the same dolomite was added to the full depth of soil at the rate of 8 tons of CaO-equivalence (13), there occurred an increase in calcium outgo; but the ratio of the enhanced calcium outgo to that of the increased outgo of magnesium was only 1:1.16 for an 8-year period. On the other hand, the losses of calcium and magnesium from 32-ton CaO-equivalent additions of dolomite over those from the unlimed soil were in a ratio of 1.70:1. In the first case, save for the initial period required for the soil to absorb the addition, the leached calcium was derived from the non-carbonate absorption complex in the absence of solid-phase dolomite. On the other hand, the calcium outgo from the 32-ton addition was derived from a system that contained as much, or more, of calcium in the absorption complex plus an excess of dolomite. The carbonated-water extraction data demonstrated that this excess of dolomite would yield a solution containing more calcium than magnesium.

Again, in a 4-year lysimeter experiment with a similar brown loam (9), the same dolomite (No. 5) was added as a 2,000-pound CaO-equivalent addition and incorporated in the upper 4 inches. In this experiment calcium and magnesium were leached out in a ratio of 2.68:1, whereas the ratio found for the percolates from the controls was 2.67:1. That is, the percolates from the dolomite addition to the upper 4-inch zone passed through an underlying untreated zone of 4 inches, after which their ratio of calcium to magnesium was the same as that carried by a full 8-inch depth of untreated soil. A corresponding ratio of only 1.37:1 was found in the percolates from subsurface-zone incorporations. Since the 1.37:1 value was derived from additions that had been made to the lower half only, this ratio may be considered as having been induced by a 4,000-pound rate, or one intermediate between the 1-ton and 8-ton additions referred to above.

After the disintegration of economic additions of this dolomite, which contained 1.11 times more calcium than magnesium, the percolates from the dolomite-treated soil contained less calcium and more magnesium than those from the untreated soil. If the absorbed calcium had suffered hydrolysis more readily than the absorbed magnesium, along with a continued solvent action upon the decreasing residues of undecomposed dolomite, the percolates would have carried more calcium than magnesium. This relationship did prevail in the previously discussed system of a dolomite suspension plus an excess of solid phase $CaCO_3$. But, since the ratio found in the soil-dolomite percolates was the opposite of that just considered, it is evident that the absorbed magnesium had entered into silicate combinations that readily hydrolyzed and exerted a protective action on the analogous calcium combinations. The evidence of this differential hydrolysis is cumulative from a number of related experiments. It is not what would be expected, however, because of the resistance that natural magnesium silicates, such as serpentine, show toward hydrolysis.

The foregoing would probably apply only to those soils that are possessed of sufficient absorbing, or "fixing," power to absorb economic additions of liming materials. In the case of light sandy soils of low colloid content, the proportion of calcium to magnesium in the leachings at a given period may be practically that yielded by the dolomite solid. For, if a soil of meagre "fixing" capacity were limed with dolomite, there would be a limited quantity of newly formed silicates to undergo the type of hydrolysis that produces a free soil water carrying more magnesium than calcium. The free water of this type of soil would therefore show a periodic content of calcium and magnesium, in line with those variations in calcium-magnesium ratios that were found in the single and replicate carbonated-water extractions of dolomite. In any case, however, the enrichment in additive magnesium could not exceed that of additive calcium.

It should also be emphasized that the periodic outgo of calcium and magnesium from a dolomite addition to a soil, as measured annually, is quite different from that which is obtained from its calcined product (9, 11). Although the cumulative calcium-magnesium outgo from a calcined CaO-MgO addition may approximate that from the raw mother rock, there is a decided difference in the speed of the outgo. There is also a marked difference between the Ca:Mg ratio in the outgo that is obtained from calcined dolomite, or corresponding additions of the separately calcined oxides of calcium and magnesium, during the first year after additions and that which is found during subsequent years. It has been shown (12) that it is during this initial annual period that a toxicity develops from excessive treatments of the pulverulent precipitated $MgCO_3$, without calcium.

SOLUBLE ACID REACTIONS WITH DOLOMITE SOLUTIONS

The persistence of a dolomite, or the speed of its disintegration in a soil, is influenced by its purity, porosity, and fineness, by rate and time of addition, type of soil, depth of incorporation, climatic factors, and the generation of acids through bacterial action. Hence, when a dolomite is mixed with the soil, there will be periods during which there will be varying excesses of solid material. In each instance, of course, the loss of calcium and magnesium from the dolomite-treated soil was accounted for not only by the action of CO_2-impregnated water, but also by nitric and sulfuric acids engendered by bacteria. It was shown in related studies (11), however, that the neutral salts accounted for only a small fraction of the total calcium-magnesium outgo during the winter months. The analysis of the leachings from various liming materials demonstrate that a large fraction of the calcium-magnesium outgo is in the bicarbonate forms. The carbonic acid of the soil system therefore produces bicarbonates of calcium and magnesium which react with the soluble acids, nevertheless the solvent action of the mobile soil acids may be directed in part against the solid dolomite particles. The extraction data demonstrated that the dolomites are dissolved by carbonated water in an ultimate calcium-magnesium ratio of 1:1, after the early depletion of any excess of calcium. What then are the ultimate products formed in a soil system when an excess of calcium-magnesium bicarbonates derived from a dolomite addition react with the soluble acids that are engendered within the soil?

The unpublished data of Bouson (2) and the present studies throw light upon this point. An initial carbonated-water solution of a dolomite was analyzed for calcium and magnesium. One-half of the joint equivalence was then met by the addition of N/20 nitric acid and the partially neutralized dilute solution was evaporated to dryness. The soluble salts were then dissolved in a few cc of water and filtered through a small filter. The filtrate and the filter were both analyzed for calcium and magnesium. The technic was duplicated by the use of N/20 hydrochloric acid.

The foregoing procedure gave the data of Table 6 from which it appears that the added acid radicals were ultimately in combinations with the magnesium. In a parallel treatment, the acids were added in amounts exactly equivalent to the $Mg(HCO_3)_2$ content of the solution. In this case, all of the added acid had combined with the magnesium and the extracted residue was exclusively $CaCO_3$. Similar results were obtained in the present studies by the use of rock No. 1 of Table 2.

TABLE 6.—*The reactions between an excess of a carbonated water solution of a dolomite and dilute mineral acids whose calcium and magnesium salts are soluble, in terms of grams of $CaCO_3$ equivalence.*

Analysis of the carbonated water solution of a dolomite*			Carbonates and soluble salts found in carbonated water solution of a dolomite after addition of acids sufficient to combine with one-half of total bicarbonates					
			HCl addition					
			Carbonates found in filter			Chlorides found in filtrates		
Ca	Mg	Ca Mg	Ca	Mg	Ca+Mg	Ca	Mg	Ca+Mg
0.0538	0.0301	0.0839	0.0401	0.0013	0.0414	0.0136	0.0273	0.0409
(No. 1, Table 2)†			0.0282	0.0036	0.0318	0.0036	0.0318	0.0354
			HNO_3 addition					
			Carbonates found in filter			Nitrates found in filtrates		
			Ca	Mg	Ca+Mg	Ca	Mg	Ca+Mg
			0.0399	0.0020	0.0419	0.0148	0.0285	0.0433

*Analyst, F. W. Bouson, 1917, 300-cc volume.
†Analyst, W. M. Shaw, 1929, 200-cc volume.

Furthermore, when one-half of the $CaCO_3$-$MgCO_3$ value was met by the addition of HCl and the excess of CO_2 in the bicarbonate solution was displaced through the aeration of the full initial volume, the amount of soluble magnesium salts corresponded to that found in the smaller volume that had been reduced by evaporation. The amount of dissolved calcium was greater, however, in the larger and aerated volume.

The preceding systems were simulated except as to the method of introducing the chlorine ions. A 100-cc neutral solution of CaCl, equivalent to 0.0450 gram of $CaCO_3$, was added to a corresponding volume and equivalence of $Mg(HCO_3)_2$. The aqueous extraction from the evaporation residue contained $MgCl_2$ equivalent to 0.430 gram of $CaCO_3$, whereas the soluble calcium was equivalent to only 0.0018 gram of $CaCO_3$.

These findings indicate that the radicals of biologically engendered mineral acids will combine preferentially with magnesium in those soil systems where dolomite additions have produced calcium-magnesium bicarbonate solutions. Any excess calcium bicarbonate is then subject to leaching, or to reaction with the solid-acid materials—assuming an absence of plant growth—dependent upon the prevailing conditions of equilibria relative to moisture and CO_2.

It would be expected, therefore, that during the persistence of undisintegrated dolomite in a soil the enhancement in magnesium outgo would be greater than that of calcium. After the disintegration of the added dolomites there comes into play another factor, that of the differential hydrolysis of the calcium-magnesium absorption complexes. If the magnesium absorption complexes hydrolyze more readily than do the calcium complexes, the outgo of magnesium would be for a time in excess of that of calcium. Such has been the case in the outgo from the soils studied.

INTERPRETATION

The foregoing data indicate that the composition and solution factors need to be considered *per se*, when dolomites are added to soils, more especially in experimental work. It is also evident that the speed of solution of a given dolomite is influenced by its Ca-Mg content and that this ratio determines the progressive proportions of additive calcium and magnesium that are absorbed by the soil. It is further indicated that a soil's content of calcium-magnesium, and the form in which the native supply of these two elements occur, are factors that influence calcium-magnesium proportions that the free soil water may be expected to carry at different periods subsequent to dolomitic additions.

The data may be interpreted to mean that in a soil with a considerable colloid content and a larger, or more readily hydrolyzable, supply of magnesium than calcium, the addition of a true dolomite would soon result in a soil system that would yield increased proportions of magnesium and decreased proportions and actual amounts of calcium to the free water. Plants grown in such a system would be expected to take up more magnesium than calcium. It was also indicated that the magnesium fraction of the calcium-magnesium bicarbonates is more apt to appear in combination with the soluble acid radicals of the soil system. It is further indicated that the continued use of dolomitic limestone can not develop an eventual magnesia-induced toxicity from accumulations of magnesium, under humid conditions, since the outgo of added magnesium exceeds that of added calcium.

SUMMARY

A study was made to determine the influence that calcium-magnesium ratios exert upon the behavior of dolomites toward carbonated water.

The higher the proportions of calcium the greater were the alkalinities of the extracts and the more quickly were equilibria obtained in initial carbonated water suspensions. The Ca:Mg ratios determined the proportions in which the two elements are initially and progressively available for absorption in the soil system.

When subjected to repeated treatments with carbonated water, the dolomites at first disintegrated through the dissolving out of $CaCO_3$ and $CaCO_3$-$MgCO_3$; but after the removal of the $CaCO_3$ excess, the dolomite residues yielded solutions in a constant Ca:Mg ratio of 1:1.

Additions of $CaCO_3$ and $MgCO_3$ to dolomite suspensions in carbonated water were found to be reciprocally repressive upon solubility and mutually protective to the solid-phase dolomite.

It is pointed out that the Ca:Mg ratio of a solid dolomite, or that of its carbonated-water solution, is not an index to the proportions of calcium and magnesium that are to be found in the soil solution after the dolomite has become a part of the soil system.

The addition of economic amounts of dolomite resulted in percolates that contained *less* calcium and *more* magnesium than did those from the untreated soil.

It was shown that acids engendered in a soil-dolomite medium will combine preferentially with magnesium to enhance the magnesium outgo from fallow soil, or to enrich the contents of growing plants.

It was pointed out that dolomites exert a protective action upon the hydrolysis of both native calcium and native potassium, the latter function being in common with that of high-calcic limestone. It was also pointed out that periodic outgo of calcium and magnesium from a dolomite addition differs from that derived from its calcined oxides.

The correlation of solubility and acid-reaction studies with lysimeter findings apparently justifies the conclusion that, under humid conditions, additions of dolomitic limestone cannot produce a toxic condition from an accumulation of magnesium *per se*, since the outgo of added magnesium exceeds that of added calcium.

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INTER-ANNUAL CORRELATION FOR PROTEIN CONTENT AND WEIGHT PER UNIT VOLUME IN WHEAT[1]

ALAN E. TRELOAR and J. ARTHUR HARRIS[2]

INTRODUCTION

The purpose of this paper is to consider the correlation between the protein content, weight per unit volume, and quality index of wheats grown in a series of districts throughout a period of years. The demonstration of the existence of significant values of such correlations is of considerable biological interest in that it demonstrates the influence of a complex of environmental conditions associated in a relatively permanent way with the individual districts.

If significant correlations be demonstrated, and if it be shown that the varieties of wheat grown in the several districts are not sufficiently differentiated to account for the inter-relationships, the conclusion must be drawn that environmental factors peculiar to individual districts—that is, varying from district to district—determine the quality of the grain produced and that these factors are of a relatively permanent nature. That this is true in a broad way is of course known as a result of general experience in crop production. It is, however, desirable to know in quantitative terms just what the magnitude of the relationship is. An ultimate task is to differentiate these individual factors, and to measure their importance in determining the protein content and other properties of the grain. A first step, however, is to ascertain whether in any given region the several districts are so clearly differentiated that the properties of the grain produced are correlated from year to year.

From the practical side, this initial step in dealing with the influence of environmental factors on the quality of the grain is of rather large importance. It is obviously desirable to be able to predict the future protein content or other commercially important characteristics of the grain crop of a district from a limited period of experience in the district.

The establishment of equations for the prediction of the properties of a future crop, for example of protein content of wheat, from the records of the given properties during a period of years must depend upon the existence of correlations between the variables under consideration in the series of districts throughout a number of crop

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[1] Contribution from the Department of Botany, University of Minnesota, Minneapolis, Minn. Received for publication May 31, 1929.

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seasons. The first essential is, therefore, to determine whether the crop properties under consideration in the given series of districts are correlated from year to year.

Given a series of plats, districts, or agricultural varieties on which any character has been measured during a period of two or more years, it is often desirable and necessary to determine the relationship between the variables under investigation in the different years. Such coefficients were early designated as inter-annual correlations (5).[3] The method has been employed with effectiveness in the investigation of the permanence of differences in the plats of an experimental field (6, 7), and in the testing of the significance of the differentiation of varieties (1, 2).

If the available records cover a long period, say *m* years, the arithmetical routine becomes laborious, since $\frac{1}{2}\, m\, (m-1)$ correlations must be determined. It may then be desirable to apply the method of intra-class and inter-class correlation (3). In such a procedure, however, the danger of spurious coefficients arising from disorderly differentiation (4) may be encountered.

While the determination of the $\frac{1}{2}\, m\, (m-1)$ inter-annual coefficients is time consuming, the importance of the present case justifies the labor. Certain points concerning the method of treatment of these data by intra-class correlation methods will be discussed in a subsequent paper.

ORIGIN OF DATA

A series of data admirably suited for a first consideration of the problem is furnished by the work of Zaharia (8).

The data given include the average protein content of the wheat, the average hectolitre weight, and the average "quality index" for 32 geographic districts for each of nine consecutive years, 1900 to 1908. It is to be noted that protein in the wheat was estimated by determining the nitrogen present and multiplying this figure by the factor 6.25, correcting the resultant value to a moisture-free basis. Thus these determinations are 9.65% (approx.) greater than they would be reported where the more customary factor of 5.7 is used. The "quality index" given by Zaharia is derived by adding twice the protein content to the hectolitre weight.

Data for May and June rainfall are also included, since variation in rainfall above the necessary minimum is generally assumed to be an important factor in determining quality as well as yield.

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[3] Reference by number is to "Literature Cited," p. 36.

TABLE 1.—*Inter-annual correlations for weight per hectolitre.*

	1900	1901	1902	1903	1904	1905	1906	1907	1908
1900		+0.4025	+0.6633	+0.6223	—0.0525	+0.5799	+0.6162	+0.1663	—0.1760
1901	+0.4025		+0.4792	+0.4469	+0.0762	+0.5422	+0.5496	+0.4888	+0.1532
1902	+0.6633	+0.4792		+0.6360	+0.1252	+0.4401	+0.5602	+0.3861	+0.1799
1903	+0.6223	+0.4469	+0.6360		+0.1954	+0.5626	+0.5799	+0.3795	+0.3199
1904	—0.0525	+0.0762	+0.1252	+0.1954		+0.0107	+0.1076	+0.2379	+0.6600
1905	+0.5799	+0.5422	+0.4401	+0.5626	+0.0107		+0.6149	+0.4923	+0.0189
1906	+0.6162	+0.5496	+0.5602	+0.5799	+0.1076	+0.6149		+0.5295	+0.1519
1907	+0.1663	+0.4888	+0.3861	+0.3795	+0.2379	+0.4923	+0.5295		+0.3971
1908	—0.1760	+0.1532	+0.1799	+0.3199	+0.6600	+0.0189	+0.1519	+0.3971	

TABLE 2.—*Inter-annual correlations for protein in wheat.*

	1900	1901	1902	1903	1904	1905	1906	1907	1908
1900		+0.6026	+0.7315	+0.5295	+0.6773	+0.5520	+0.1501	+0.6295	+0.4009
1901	+0.6026		+0.6687	+0.6427	+0.5458	+0.5557	+0.0235	+0.4347	+0.3364
1902	+0.7315	+0.6687		+0.6474	+0.5839	+0.6642	+0.3657	+0.7293	+0.4653
1903	+0.5295	+0.6427	+0.6474		+0.3921	+0.3558	+0.0859	+0.4032	+0.1403
1904	+0.6773	+0.5458	+0.5839	+0.3921		+0.2559	+0.1896	+0.7175	+0.7959
1905	+0.5520	+0.5557	+0.6642	+0.3558	+0.2559		+0.3240	+0.3649	+0.2028
1906	+0.1501	+0.0235	+0.3657	+0.0859	+0.1896	+0.3240		+0.4993	+0.3509
1907	+0.6295	+0.4347	+0.7293	+0.4032	+0.7175	+0.3649	+0.4993		+0.7667
1908	+0.4009	+0.3364	+0.4653	+0.1403	+0.7959	+0.2028	+0.3509	+0.7667	

TABLE 3.—*Inter-annual correlations for quality index.*

	1900	1901	1902	1903	1904	1905	1906	1907	1908
1900		+0.6446	+0.8284	+0.6322	+0.7742	+0.6965	+0.4980	+0.5889	+0.2992
1901	+0.6446		+0.7428	+0.5712	+0.6083	+0.6692	+0.5360	+0.4860	+0.2982
1902	+0.8284	+0.7428		+0.6453	+0.7725	+0.8250	+0.6556	+0.5844	+0.3630
1903	+0.6322	+0.5712	+0.6453		+0.5637	+0.6122	+0.3572	+0.2277	+0.0586
1904	+0.7742	+0.6083	+0.7725	+0.5637		+0.6350	+0.6085	+0.5254	+0.4623
1905	+0.6965	+0.6692	+0.8250	+0.6122	+0.6350		+0.5257	+0.5366	+0.1706
1906	+0.4980	+0.5360	+0.6556	+0.3572	+0.6085	+0.5257		+0.5148	+0.5887
1907	+0.5889	+0.4860	+0.5844	+0.2277	+0.5254	+0.5366	+0.5148		+0.5640
1908	+0.2992	+0.2982	+0.3630	+0.0586	+0.4623	+0.1706	+0.5887	+0.5640	

TABLE 4.—*Inter-annual correlations for May rainfall.*

	1900	1901	1902	1903	1904	1905	1906	1907	1908
1900		+0.2113	—0.0963	+0.0478	—0.1986	+0.2388	+0.2273	—0.0248	+0.1261
1901	+0.2113		+0.5913	+0.3828	+0.1199	+0.4043	+0.7215	+0.1079	+0.4484
1902	—0.0963	+0.5913		+0.4725	—0.2197	—0.0446	+0.5303	+0.1358	+0.0210
1903	+0.0478	+0.3828	+0.4725		—0.1920	+0.2057	+0.6493	—0.0544	+0.4071
1904	—0.1986	+0.1199	—0.2197	—0.1920		+0.2938	—0.1607	+0.1480	+0.1398
1905	+0.2388	+0.4043	—0.0446	+0.2057	+0.2938		+0.3196	—0.3297	+0.2870
1906	+0.2273	+0.7215	+0.5303	+0.6493	—0.1607	+0.3196		—0.0632	+0.4912
1907	—0.0248	+0.1079	+0.1358	—0.0544	+0.1480	—0.3297	—0 0632		+0.0183
1908	+0.1261	+0.4484	+0.0210	+0.4071	+0.1398	+0.2870	+0.4912	+0.0183	

TABLE 5.—*Inter-annual correlations for June rainfall.*

	1900	1901	1902	1903	1904	1905	1906	1907	1908
1900		+0.0806	—0.0555	—0.1086	—0 0330	+0.2132	—0.2583	+0.5967	+0.1097
1901	+0.0806		—0.3265	—0.1923	+0.0850	+0.0179	—0.3275	—0.0292	—0.1725
1902	—0.0555	—0.3265		+0.7748	+0.2431	+0.2826	+0.5592	+0.2101	+0.3301
1903	—0.1086	—0.1923	+0.7748		+0.0700	+0.0609	+0.4563	+0.1221	+0.3835
1904	—0.0330	+0.0850	+0.2431	+0.0700		—0.3116	—0.1162	+0.2345	—0.2756
1905	+0.2132	+0.0179	+0.2826	+0.0609	—0.3116		+0.3859	+0.0012	+0.0366
1906	—0.2583	—0.3275	+0.5592	+0.4563	—0.1162	+0.3859		—0.2731	+0.1823
1907	+0.5967	—0.0292	+0.2101	+0.1221	+0.2345	+0.0012	—0.2731		+0.1721
1908	+0.1097	—0.1725	+0.3301	+0.3835	—0.2756	+0.0366	+0.1823	+0.1721	

All possible correlations[4] between the values of the same variable in the several years covered by the records are given in Tables 1 to 5. The average value of these components have been determined in two ways. First, the average of the correlations between each year and every other year of the period of nine years have been determined and are presented in Table 6. Second, the averages of the correlations between years separated by varying periods of time have been calculated and are set forth in Table 7. Reasons for the use of both methods of treatment will be apparent later.

RESULTS

The correlations between the weight per hectolitre of the wheats of the series of districts for all the possible combinations of years are shown in Table 1. Of the 36 coefficients, 34 are positive as compared with 2 which are slightly negative (—0.0525 and —0.1760). The positive coefficients range from +0.0107 to +0.6633. The average value of the two negative coefficients is —0.1143; that of the 34 positive coefficients, +0.3827; while that of the whole series of 36 coefficients is +0.3653. From Table 6 it appears that the average correlations for each of the years with the other years of the group are positive, the averages ranging in magnitude from +0.1734 to +0.4656.

TABLE 6.—*Average inter-annual correlation by years.*

Year	Hectolitre weight	Protein in wheat	Quality index	May rainfall	June rainfall
1900	+0.3527	+0.5342	+0.6203	+0.0665	+0.0681
1901	+0.3916	+0.4745	+0.5682	+0.3734	—0.1081
1902	+0.4310	+0.6053	+0.6747	+0.1738	+0.2522
1903	+0.4656	+0.3982	+0.4558	+0.2398	+0.1958
1904	+0.1734	+0.5189	+0.6168	—0.0087	—0.0130
1905	+0.4063	+0.4083	+0.5829	+0.1718	+0.0859
1906	+0.4613	+0.2495	+0.5360	+0.3394	+0.0761
1907	+0.3868	+0.5682	+0.5023	—0.0078	+0.1293
1908	+0.2185	+0.4337	+0.3519	+0.2424	+0.0958
1900–08	+0.3653	+0.4652	+0.5447	+0.1767	+0.0869

TABLE 7.—*Average inter-annual correlations for progressive intervals of separation.*

Period apart	No. of Coeffs.	Hectolitre weight	Protein in wheat	Quality index	May rainfall	June rainfall
1 year	8	+0.4082	+0.5196	+0.6045	+0.2064	+0.0716
2 years	7	+0.3642	+0.4599	+0.6455	+0.0390	+0.0177
3 years	6	+0.3292	+0.4576	+0.5198	+0.2012	+0.1644
4 years	5	+0.4179	+0.5595	+0.5578	+0.1643	+0.0781
5 years	4	+0.4589	+0.3613	+0.4689	+0.3758	+0.1198
6 years	3	+0.4283	+0.3501	+0.4490	+0.1187	+0.0142
7 years	2	+0.1597	+0.4829	+0.4435	+0.2118	+0.2121
8 years	1	—0.1760	+0.4009	+0.2992	+0.1261	+0.1097

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[4] In three districts for 1900 and in one for 1905 data are not available. Correction has been made for these differences in number of districts per annum, and weighting given to the various years in determining the averages.

There can, therefore, be no question that the weight per unit volume of Roumanian wheats grown in the 32 districts is distinctly and significantly differentiated from district to district, and that this differentiation is relatively permanent. With the exception of the correlations between 1900 and 1904 and between 1900 and 1908, the positive correlation is evident for all pairs of years.

Similar relationships are shown for the protein content of the wheat, as set forth in Table 2. These coefficients are positive throughout and on the average are slightly larger than those for weight per unit volume. The 36 coefficients range from +0.0235 to +0.7959. The averages of the eight coefficients for each of the nine individual years range from +0.2495 to +0.6053, with a general average for the 36 coefficients of +0.4652.

We have no brief to hold for the "quality index" given by Zaharia, but have determined the coefficients in order to present a complete and unprejudiced statement of the results obtainable from the data.

The coefficients set forth in Table 3 are without exception positive in sign, ranging from +0.0586 to +0.8284. The averages of the coefficients by years, as given in Table 6, range from +0.3519 to +0.6747, with a general average of +0.5447 for the 36 coefficients representing all possible combinations of years.

The foregoing results can leave no doubt as to the existence of a medium positive correlation between years for the weight per unit volume, protein content, and "quality index" of wheats grown in the various subdivisions of the Roumanian territory for 1900 to 1908, inclusive.

It is now worth while to enquire whether these districts are so differentiated with respect to May and June rainfall that comparable correlations are to be found for these climatological variables. If correlations of the same magnitude or of materially higher magnitude were found for rainfall during these presumably critical months, it would be reasonable to assume that the differences in quality of grain might be primarily due to these factors. The actual results appear in Tables 4 and 5.

A glance at these tables shows that the coefficients are low in magnitude and irregular in sign. For May rainfall, 10 of the coefficients are negative as compared with 26 which are positive. For June rainfall, 13 coefficients are negative as compared with 23 which are positive. The average by years of correlations for May rainfall is slightly negative for two years (1904 and 1907) and that for the correlations for June rainfall is slightly negative for 1901 and 1904. The average correlation for all combinations of years is +0.1767 for May rainfall and +0.0809 for June rainfall. It is, therefore, quite evident that the correlation for the rainfall of the districts from year to year is much smaller than that for the measures of quality of wheat produced.

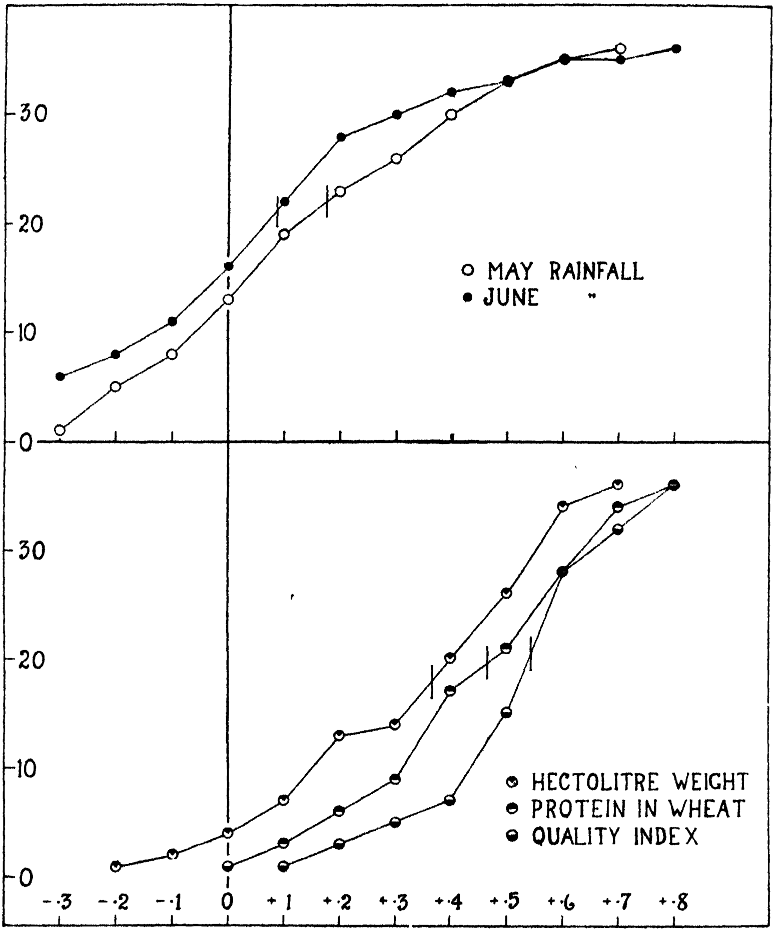

FIG. 1.—Frequency curves of inter-annual correlations for May and June rainfall, hectolitre weight, protein in wheat, and quality index.

The differences in the five groups of correlations considered may be conveniently represented graphically by summing the frequencies of correlations up to and including the coefficients of any given magnitude. The distributions of the frequencies are shown in Fig. 1. Here the scale of abscissae represents the magnitude of negative and positive correlations. The diagram is broken into two parts with two scales of ordinates, each showing the total number of coefficients up to the magnitude shown on the abscissal scale.

The upper portion of the diagram shows that a material fraction of the coefficients for rainfall are zero or lower. Fifty-one of the 72 coefficients are less than +0.25 in magnitude.

The lower section of the diagram shows that practically none of the coefficients are less than zero. Only 21 out of the 108 coefficients are less than +0.25 in magnitude and the frequencies rise rapidly with each positive increment of the correlation coefficient.

An examination of the individual coefficients (Tables 1 to 5) and the table of the averages by years (Table 6) indicates that the correlations may differ from year to year. Thus, the coefficients for weight per hectolitre for 1904 and 1908 are generally low. The two negative constants occur in these years. The averages of the correlations for 1904 and 1908 with other years are in one case slightly less and in the other case slightly more (+0.1734 and +0.2185) than half as large as the general average (+0.3653). Thus these two years seem to be aberrant in their inter-correlations with other years. It is interesting to note that the correlation between weight per hectolitre in these two years (1904 and 1908) is +0.6600, which is next to the highest value in the whole series of 36 coefficients.

The correlations for protein in the wheat are apparently more uniform, but in this case the coefficients for 1903 and 1906 seem to be slightly lower than the other values. Since the general problem of the significance of such differences will probably be taken up at another time, it will not be discussed here further than to point out that for certain combinations of years the inter-annual correlations may be higher than for other combinations. This does not mitigate against the general conclusion that if the correlations are sufficiently large that reasonable predictions of the quality of wheat produced per district should ultimately be possible.

The averages of the correlations classified according to the period of separation of the yields upon which the coefficients are based are presented in Table 7. They are of interest in showing that in general there is no attenuation of the magnitude of the coefficients with increase in the period of separation. In evaluating the apparent exceptions to this rule in the case of the coefficients based on periods separated by seven intervening years, it must be recalled that there is only a single determination of the kind possible for a period of nine years, and that for weight per bushel, all of the coefficients for 1908 tend to be low.

SUMMARY

The possibility of the prediction of the quality (protein content, weight per unit volume, quality index, etc.) of the wheat crop of the individual districts of a large geographic area must depend on the existence of significant correlations between these variables in different years.

Statistical analysis of the data for average weight per hectolitre, protein content, and quality index of the Roumanian wheats tabled by Zaharia for the nine year period 1900 to 1908 shows average values of +0.3653 for weight per unit volume, +0.4652 for protein content, and +0.5447 for quality index. The inter-annual correlations for rainfall are low, averaging only +0.1767 for May and +0.0869 for June.

It is significant to note that, while these correlations represent interrelationships covering a range of nine crop years, the magnitudes of the correlations are not greatly affected by the period of separation of the two variables.

With inter-annual coefficients of the magnitude of those determined herein, the prediction of future quality of wheat crops should be possible within a reasonable degree of accuracy.

While this paper is based on Roumanian data, the primary consideration is that of the principle involved. There can be no reasonable doubt that similar results will be found for districts of other geographic areas. The magnitude of the correlation will depend upon the extent of differentiation of the districts in soil and climatic conditions.

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ABORTIVE SEEDS IN SOYBEANS[1]

C. M. WOODWORTH[2]

INTRODUCTION

The occurrence of abortive seeds in the soybean has been observed at various times during the last few years. Due to interest in other problems in this plant, however, no particular study was made of their occurrence until the fall of 1928. During the course of some studies on seed quality in the progeny of 100 single-plant selections of the Illini soybean, we were struck with the fact that so many of the pods showed one or more abortive seeds. It seemed worth while to determine the relative frequency of abortive seeds in this material, as well as the location of such seeds in the pod and on the plant. It is the purpose of this paper to set forth the results of this study.

DESCRIPTION OF ABORTIVE SEEDS

The presence in the soybean pod of abortive seeds is easily recognized by the flattened appearance of the pod where they occur (Fig. 1). They consist of undeveloped or poorly developed seeds that for some reason have not been able to attain normal size. An examination of many "aborts" showed that all but the very smallest possessed an embryo, and that, therefore, fertilization had occurred. The shrivelled, dwarfed appearance was due, in these cases, to the lack of development of the cotyledons.

EXTENT OR AMOUNT OF ABORTIVENESS

Halsted[3] studied abortiveness in soybeans with particular reference to the location of abortive seeds in the pod. Pods were classified and counted from three varieties, namely, Early Brown, Ito San, and Wilson. In a total of 4,382 pods, there were 9,584 seeds, of which 1,259 or 13.14% were abortive. Approximately one-eighth, therefore, of the total number of ovules failed to develop into normal seed. The percentage of abortiveness in Early Brown was 15; in Wilson, 6.75; and in Ito San, 14.2.

[1] Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication June 11, 1929.

[2] Chief in Plant Breeding.

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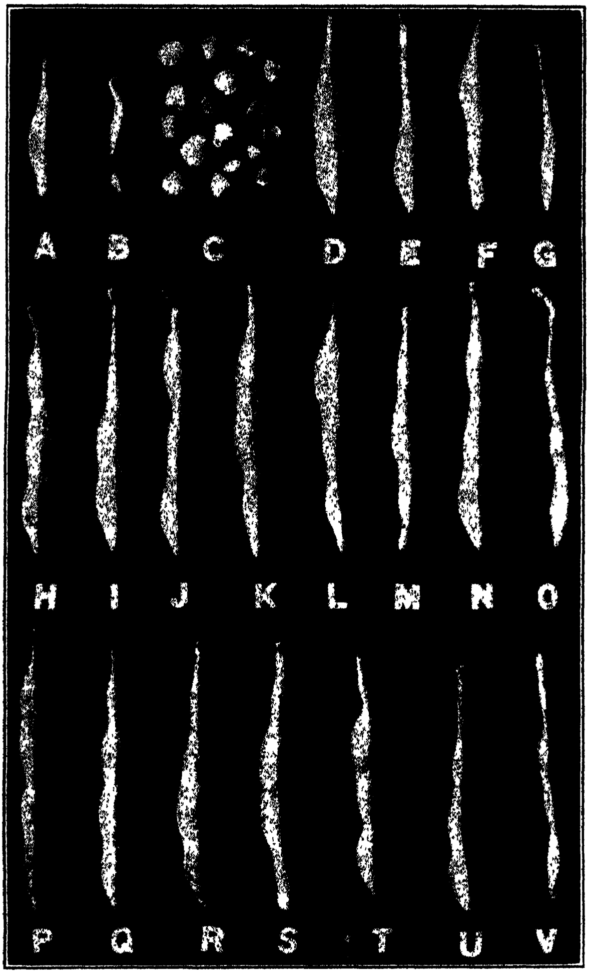

FIG. 1.—Appearance of abortive seeds and their location in soybean pods.

A. One-seeded pod, non-abortive.
B. One-seeded pod, abortive.
C. Abortive seeds ranging from very small shriveled masses to half-grown seeds.
D. Two-seeded pod, none-abortive.
E. Two-seeded pod, basal seed abortive.
F. Two-seeded pod, tip seed abortive.
G. Two-seeded pod, both seeds abortive.
H. Three-seeded pod, none-abortive.
I. Three-seeded pod, basal seed abortive.
J. Three-seeded pod, middle seed abortive.
K. Three-seeded pod, tip seed abortive.
L. Three-seeded pod, middle and tip seeds abortive.
M. Three-seeded pod, basal and tip seeds abortive.
N. Three-seeded pod, basal and middle seeds abortive.
O. Three-seeded pod, all three seeds abortive.
P. Four-seeded pod, none-abortive.
Q. Four-seeded pod, basal seed abortive.
R. Four-seeded pod, basal and second seeds abortive.
S. Four-seeded pod, basal and tip seeds abortive.
T. Four-seeded pod, basal and third seeds abortive.
U. Four-seeded pod, basal, second, and third seeds abortive.
V. Four-seeded pod, all four seeds abortive.

In 1928, at the Illinois Agricultural Experiment Station, 100 progeny rows were grown from as many single-plant selections of the Illini variety made in the fall of 1927. The original purpose of making these selections was to determine whether any variations could be detected in the direction of resistance of the pods and seeds to unfavorable weather conditions. For this study, half of each row was left in the field till the latter part of November, and pods were picked from the standing plants at intervals to determine whether exposure to rain and low temperatures had any detrimental effect on the quality and germination of the seed. The other half of each row was harvested soon after the beans were ripe (Sept. 20) in order to have good seed to continue any selections that proved best on the basis of quality.

Casual examination of the plants harvested in September revealed the occurrence of seed abortiveness to an extent that appeared to warrant detailed study. Twenty-five plants were taken from each row at random and the pods carefully picked off by hand and placed in paper sacks. Later the pods were classified into one-, two-, three-, and four-seeded pods, and each of these was further classified according to the number of abortive seeds found (Fig. 1, A, B, D—V).

The percentage of seed abortion in this material was calculated as follows: After the pods were classified as above explained, the total number of seeds was determined for the 25 plants of each row or selection. This was designated the potential seed production. Then the number of abortive seeds was determined, and the total number of seeds divided into the number of abortive seeds gave the percentage of seed abortion.

A similar procedure was followed in determining the amount of seed abortion on single plants of several other strains of soybeans that were grown on a different field from that on which the Illini selections were grown. All but one of these strains originated as single-plant selections from the A. K. variety, which was also the source of the Illini. The exception to this statement is the Tall Manchu which was selected from the Early Manchu because of its

TABLE 1.—*Varietal differences in mean percentage of abortive seeds.*

Variety or strain	Number of plants	Mean percentage abortive seeds	Percentage range
A. K. 2	72	14.4±.271	6–26
A. K. 92	83	17.3±.472	5–42
A. K. 102	120	17.3±.386	3–35
A. K. 114	81	9.4±.383	2–30
A. K. 125	120	20.8±.385	8–39
A. K. 146	142	20.6±.381	2–44
Tall Manchu	175	12.5±.299	2–36
Illini	2500	22.2±.148	16–26

greater length of main stem. Table 1 gives the average percentage of abortion for the strains studied, including the Illini.

These results confirm those of Halsted, namely, that certain varieties differ considerably and significantly in the percentage of abortive seeds. The Illini does not show so great a range as the other strains probably because the individual plants were not considered separately as were the plants of the other strains, but rather in groups of 25 (25 plants from each of 100 rows). All the strains, with the exception of the Illini, were grown on the same field and the soil was in a good state of fertility. The Illini soybeans were grown on a less productive soil, but they produced a good crop. All strains were well inoculated.

RELATION OF ABORTIVENESS TO NUMBER OF SEEDS IN POD

It is well to inquire whether seed abortion is distributed among the pod types (based on number of seeds) according to chance. Soybean pods are one-, two-, three-, and four-seeded (Fig. 1, A, D, H, P). The one- and four-seeded types are relatively few in number, the two- and three-seeded pods predominating. The distribution of seed abortion among these pod types is shown in Table 2 for all the strains studied. In order, however, to determine how closely this approached a chance distribution, the data for the Illini, being the most extensive, were studied particularly. In this variety the average percentage of abortiveness was 22.2, or a ratio of approximately 3.5 none-abortive (good) seeds to 1 abortive. In one-seeded pods there should be 3.5 times as many none-abortive as abortive. In two-seeded pods, the classes none-abortive, one-abortive, and two-abortive should be in the ratio of 12.25 to 7.0 to 1.0, respectively; in the case of three-seeded pods, the classes, none-abortive, one-abortive, two-abortive, and three-abortive should be in the ratio of 42.875 to 36.75 to 10.5 to 1.0, respectively; and in the case of four-seeded pods the classes none-abortive, one-abortive, two-abortive, three-abortive, and four-abortive should be in the ratio of 150.0525 to 171.5 to 73.5 to 14 to 1. These ratios are determined by expanding the binomial $(3.5+1)$ to the power represented by the number of seeds in the pod; as, one, two, three, or four.

Comparisons of observed numbers with the expected on the basis of the above ratios are shown in Table 3. Pods were found in all the classes and in approximately the expected numbers, though when the χ^2 test for goodness of fit was applied, χ^2 was calculated to be 776.49 with consequently a very low value for P. On the basis of this test, therefore, we should conclude that the deviations of the observed from expected results are too wide to be accounted for by chance alone. It will be observed from the table that it is the

TABLE 2.—*Number of pods with none to four abortive seeds as distributed among the one- to four-seeded pod types.*

Pod types	Variety or strain							
	A. K. 125	A. K. 102	A. K. 92	A. K. 2	A. K. 114	Tall Manchu	A. K. 146	Illini
				One-seeded Pods				
None abortive .	93	88	44	93	249	549	161	649
One abortive ..	10	5	8	8	4	50	13	129
				Two-seeded Pods				
None abortive .	563	590	409	426	681	2,740	801	7,056
One abortive	204	172	137	155	141	636	266	4,275
Two abortive..	61	49	39	23	10	67	100	548
				Three-seeded Pods				
None abortive.	1,568	1,692	1,274	1,215	1,015	2,530	1,793	20,975
One abortive .	1,009	701	617	552	237	884	1,065	20,191
Two abortive...	187	133	111	77	54	230	214	3,945
Three abortive..	160	139	83	27	24	60	179	843
				Four-seeded Pods				
None abortive	22	20	14	13	6		9	155
One abortive .	16	10	7	14	2		8	210
Two abortive. .	1		5					56
Three abortive..							1	14
Four abortive. .	2	1					1	1
Number of plants	120	120	83	72	81	175	142	2,500

three-seeded pod classes that contribute most to the high value of χ^2. Why this is so is not apparent at present, particularly in view of the large numbers observed in these pod classes.

TABLE 3.—*Showing comparison of observed pod type frequencies with calculated for Illini variety.*

Pod types	Observed (o)	Calculated (c)	Expected ratio	$\frac{(o-c)^2}{c}$
	One-seeded Pods			
None abortive.	649	605	3.5	3.20
One abortive .. .	129	173	1.0	11.20
	Two-seeded Pods			
None abortive	7,056	7,191	12.25	2.54
One abortive	4,275	4,109	7.0	6.71
Two abortive	548	587	1.0	2.60
	Three-seeded Pods			
None abortive..	20,975	21,609	42.875	18.60
One abortive	20,191	18,522	36.75	150.39
Two abortive	3,945	5,292	10.50	342.86
Three abortive...... ...	843	504	1.0	228.02
	Four-seeded Pods			
None abortive..........	155	159	150.0625	.10
One abortive	210	183	171.50	4.00
Two abortive..........	56	78	73.50	6.20
Three abortive.........	14	15	14.0	.07
Four abortive..........	1	1	1.0	.00
			$\chi^2 =$	776.49

RELATION OF ABORTIVENESS TO POSITION IN POD

As stated in the beginning, Halsted[4] gave particular attention to the relation of abortiveness to position in the pod. Table 4 has been made up from his data and includes also data on 75 plants

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[4] *Loc. cit.* (first reference).

(3 rows of 25 plants each) of Illini soybeans. In general, Halsted's data and ours are similar, with the exception that he records no pods in which all the seeds are abortive. The outstanding feature shown by Table 4 is the great preponderance of abortiveness in the basal seed (Fig. 1, E, I, Q). Halsted[5] states, "Twenty-six % of 4,382 pods have one or more abortive ovules, and of these 1,149 pods, 71.5% have an abortive basal ovule, and 31.9% are with aborts at the tip."

TABLE 4.—*Relation of abortiveness to position in the pod.*

Pod types	Variety or strain			
	Early Brown*	Wilson*	Ito San*	Illini
	One-seeded Pods			
None abortive	446	51	308	19
One abortive	—	—	—	2
	Two-seeded Pods			
None abortive	682	354	445	215
One abortive, base	168	24	123	87
One abortive, tip	62	12	45	16
Two abortive	—	—	—	12
	Three-seeded Pods			
None abortive	347	300	300	626
One abortive, base	234	44	113	498
One abortive, middle	75	16	36	39
One abortive, tip	17	11	22	32
Two abortive, base and middle	34	8	37	82
Two abortive, base and tip	8	5	11	26
Two abortive, middle and tip	2	—	2	10
Three abortive	—	—	—	21
	Four-seeded Pods			
None abortive	—	—	—	5
One abortive	6	1	2	7
One abortive, next to base	5	—	—	—
One abortive, next to tip	23	—	—	—
Two abortive, base and next to base	1	—	—	2
Two abortive, base and next to tip	2	—	—	—
Two abortive, base and tip	—	—	—	1
Four abortive	—	—	—	1
Totals	2,112	826	1,444	1,701

*Data from N. J. Agr. Exp. Sta. Ann. Rpt., 1914:321–325.

In another study which he made of the Wilson variety, including over 3,000 pods, the abortiveness in the basal position of two-seeded pods was 90% and in three-seeded pods 79%. Similarly, in another study of the Ito San variety, he found that in 2,480 two-seeded pods the basal position had 83.8% of all the aborts and the tip position only 16.2%. These findings are also brought out by studies made at this station on the Illini variety. As shown in Table 4, of the 115 two-seeded pods having abortive seeds, 87, or 75.65%, are in the basal position (Fig. 1, E); 16, or 13.9%, in the tip position (Fig. 1, F); and 12, or 10.45%, had both seeds abortive (Fig. 1, G). Similarly,

[5] *Loc. cit.* (second reference).

of the 569 three-seeded pods having one seed abortive, 498, or 87.52%, are abortive in the basal position (Fig. 1, I); 39, or 6.85%, in the middle position (Fig. 1, J); and 32, or 5.63%, in the tip position (Fig. 1, K). Also, certain combinations of positions are more favored for abortiveness than others. Thus, of 118 three-seeded pods with two abortive seeds, 82, or 69.49%, are abortive in base and middle positions (Fig. 1, N); 26, or 22.03%, are abortive in base and tip positions (Fig. 1, M); and only 10, or 8.48%, in the middle and tip positions (Fig. 1, L).

This situation is quite different from what we would expect on a simple probability basis. In two-seeded pods, for example, there are two types of pods with one seed abortive, *viz.*, (1) that with basal seed abortive and (2) that with tip seed abortive. Hence, abortiveness of one seed in this case can happen in one of two ways, either of which would appear to be equally likely to occur. Similarly, in three-seeded pods, there are three types of pods with one seed abortive, *viz.*, (1) that with basal seed abortive, (2) that with middle seed abortive, and (3) that with tip seed abortive. Abortiveness of one seed can, therefore, happen in one of three ways, one or another of which would appear to be equally likely to occur. However, an examination of the actual frequencies of these pod classes reveals such a wide deviation from equality that it is useless to apply a test for goodness of fit. Obviously, a principle of development is at work here with such preponderating influence as to remove the problem entirely from the realm of chance.

Furthermore, a study of the abortive seeds themselves reveals differences connected with their positions in the pod (Table 5 and Fig. 2). In two- and three-seeded pods with one seed abortive, the tip seed is the least developed of the aborts. This is rather surprising in view of the fact that this position is favored over the others with respect to amount or extent of abortiveness as was shown above. The abort at the tip in two-seeded pods averaged 0.0029 gram, while the abort at the base averaged 0.0047 gram, almost twice as much. Similarly, the abort at the tip in three-seeded pods was lowest in weight, being only 0.0038 gram compared with 0.0050 gram for the abort at the middle and 0.0048 gram for the abort at the base.

On the other hand, in the case of two abortive seeds in three-seeded pods, the abort at the tip, or the abort nearer the tip, is the larger. Thus, in pods with middle and tip seeds abortive, the middle abort averaged 0.0018, while the tip abort averaged 0.0256. In pods with base and tip seeds abortive, the base abort averaged 0.0036, while the tip abort averaged 0.0043. In pods with base and middle seeds abortive, the base abort weighed an average of 0.0020 gram and the middle abort 0.0086 gram. Much the same situation is shown when we compare the weights of aborts in two- and three-seeded

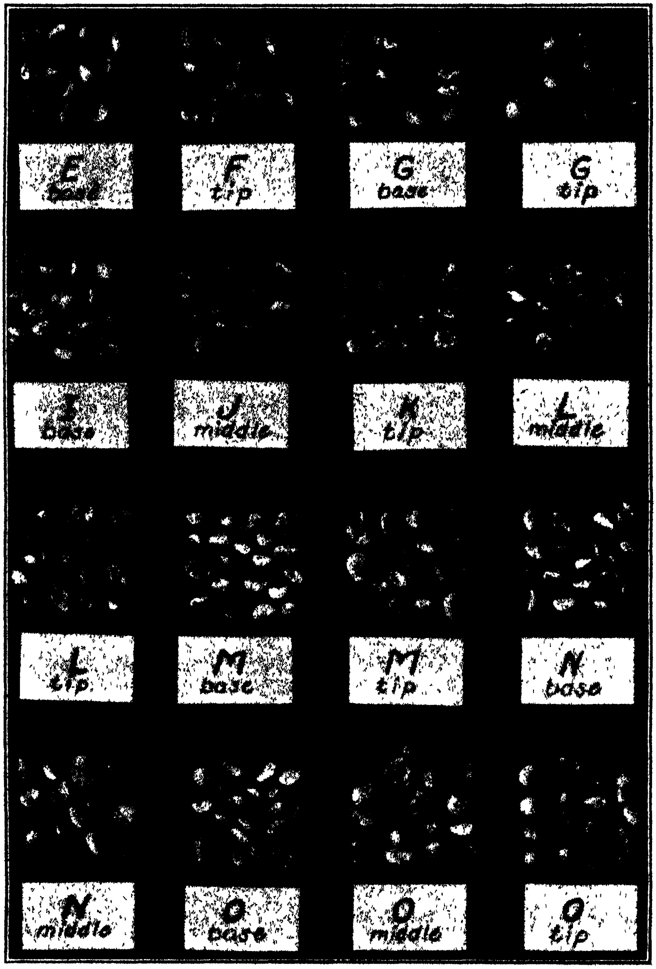

FIG. 2.—Degree of development of abortive seeds in relation to position in the pod.

E, F. Abortive seeds from two-seeded pods, only one seed abortive
G. Abortive seeds from two-seeded pods, both seeds abortive.
I, J, K. Abortive seeds from three-seeded pods, only one seed abortive.
L, M, N. Abortive seeds from three-seeded pods with two abortive seeds.
O. Abortive seeds from three-seeded pods, all three seeds abortive.

pods in which all seeds are abortive. In two-seeded pods, the base abort averaged 0.0042 gram, while the tip abort averaged 0.0186. In three-seeded pods, the average weights of base, middle, and tip aborts were, respectively, 0.0032, 0.0113, and 0.0118 gram.

Studies on the normal seeds in this material brought out certain other interesting comparisons. It was thought that in pods containing one or more aborts the normal seeds have an exceptional opportunity to develop and, therefore, should attain a larger size and weight than those in pods containing no abortive seeds. However, just the opposite was found to be true. The normal seeds in one-, two-, three-, and four-seeded pods containing no abortive seeds

TABLE 5.—*Degree of development determined by average weight in grams of normal seeds and abortive seeds in relation to position in the pod.*

	Type of pod and seed	Position	Number of seeds	Average weight of seeds, grams
A.	One-seeded, none abortive	———	23	0.1260
D.	Two-seeded, none abortive	base	215	0.1283
	Two-seeded, none abortive	tip	215	0.1341
E.	Two-seeded, basal seed abortive	base	117	0.0047
	Two-seeded, basal seed abortive	tip	118	0.1161
F.	Two-seeded, tip seed abortive	base	13	0.1184
	Two-seeded, tip seed abortive	tip	13	0.0029
G.	Two-seeded, both seeds abortive	base	13	0.0042
	Two-seeded, both seeds abortive	tip	13	0.0186
H.	Three-seeded, none abortive	base	566	0.1218
	Three-seeded, none abortive	middle	566	0.1400
	Three-seeded, none abortive	tip	566	0.1338
I.	Three-seeded, basal seed abortive	base	600	0.0048
	Three-seeded, basal seed abortive	middle	600	0.1186
	Three-seeded, basal seed abortive	tip	600	0 1213
J.	Three-seeded, middle seed abortive	base	39	0.1273
	Three-seeded, middle seed abortive	middle	38	0.0050
	Three-seeded, middle seed abortive	tip	39	0.1355
K.	Three-seeded, tip seed abortive	base	49	0.1256
	Three-seeded, tip seed abortive	middle	49	0.1379
	Three-seeded, tip seed abortive	tip	49	0.0038
L.	Three-seeded, middle and tip seeds abortive	base	13	0.1261
	Three-seeded, middle and tip seeds abortive	middle	13	0.0018
	Three-seeded, middle and tip seeds abortive	tip	13	0.0256
M.	Three-seeded, basal and tip seeds abortive	base	50	0.0036
	Three-seeded, basal and tip seeds abortive	middle	50	0.1161
	Three-seeded, basal and tip seeds abortive	tip	50	0.0043
N.	Three-seeded, basal and middle seeds abortive	base	90	0.0020
	Three-seeded, basal and middle seeds abortive	middle	90	0.0086
	Three-seeded, basal and middle seeds abortive	tip	90	0.1182
O.	Three-seeded, all three seeds abortive	base	28	0.0032
	Three-seeded, all three seeds abortive	middle	26	0.0113
	Three-seeded, all three seeds abortive	tip	28	0.0118
P.	Four-seeded, none abortive	base	8	0.1235
	Four-seeded, none abortive	second	8	0.1477
	Four-seeded, none abortive	third	8	0.1428
	Four-seeded, none abortive	tip	8	0.1200
Q.	Four-seeded, basal seed abortive	base	4	0.0043
	Four-seeded, basal seed abortive	second	4	0.1200
	Four-seeded, basal seed abortive	third	4	0.1250
	Four-seeded, basal seed abortive	tip	4	0.1188

numbered 2,183 and averaged 0.1317 gram, while the normal seeds in pod types containing one or more abortive seeds numbered 1,672 and averaged only 0.1207 gram. It is believed that the large number of seeds involved in this comparison justifies us in attaching significance to the difference of 0.0110 gram in average weight between the two classes of normal seeds. From the standpoint of good seed, therefore, the seeds from pods containing no aborts are to be preferred.

In pods containing no abortive seeds, it is interesting also to compare the average weights of normal seeds in relation to their position in the pod. In two-seeded pods (Table 5) the tip seeds are the heavier, averaging 0.1341 gram compared with 0.1283 gram for the base seeds. In three-seeded pods, however, the middle seed is heaviest, averaging 0.1400 gram as compared with 0.1218 for the base and 0.1338 gram for the tip. The data on four-seeded pods show the same relations, though they are based on only eight pods. Thus, the base, second, third, and tip seeds averaged, respectively, 0.1235, 0.1477, 0.1428, and 0.1200 gram.

On the basis of the evidence presented, it may be concluded that there is a very close relation between extent of abortiveness and position in the pod and between degree of development and position in the pod. With respect to amount of abortiveness, the basal seed is at a disadvantage; the tip seed is the most favored; and in a three-seeded pod, the middle seed is slightly less favored than the tip. Extent of abortiveness seems, therefore, to decrease progressively from the base to the tip of the pod. With respect to degree of development, the situation is different. Much depends on whether all or only one or two seeds are abortive. If all seeds are abortive, development is the better in the tip position in two-seeded pods; and best in tip position in three-seeded pods. With two seeds abortive in three-seeded pods, the tip is favored over the middle and base; and in pods with base and middle seeds abortive, the middle position, that nearer the tip, is the better developed. However, with only one seed abortive, the tip position seems to be at a disadvantage, as in two-seeded pods the base is better developed and in three-seeded pods the middle is best developed. Finally, in pods containing no abortive seeds, the tip seeds in two-seeded pods and the middle seed or seeds in three- and four-seeded pods attain the highest weight.

RELATION OF ABORTIVENESS TO POSITION ON PLANT

It is next in order to inquire whether there is any relation between abortiveness of seeds and the part of the plant upon which they are borne. Halsted[6] made a preliminary study of this question, using 10 plants of the Ito San variety. The plants were cut into three equal parts called (a) lower third, (b) middle third, and (c) top third. For these plant parts the percentages of abortive seeds were 15, 17.7, and 32.2, respectively; and Halsted concluded that abortive seeds increased from the lower to the upper third of the plant.

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[6] *Loc. cit.* (first reference).

Results on the Illini soybeans were somewhat at variance with the results of Halsted. Pods were picked off each of 25 plants, beginning at the base of the plant and going toward the tip, recording for each node of the main stem the pod number and classifying the pods as to total number of seeds and number of abortive seeds. The percentage of abortive seeds was then calculated for each node of the plant. Results are given in Table 6 and presented graphically in Fig. 3. The graph is seen to be roughly U-shaped, with high points at base and tip and low points at middle of plant. Therefore, on the basis of these results, the middle of the plant showed the least abortiveness, the base next, and the tip of the plant the most.

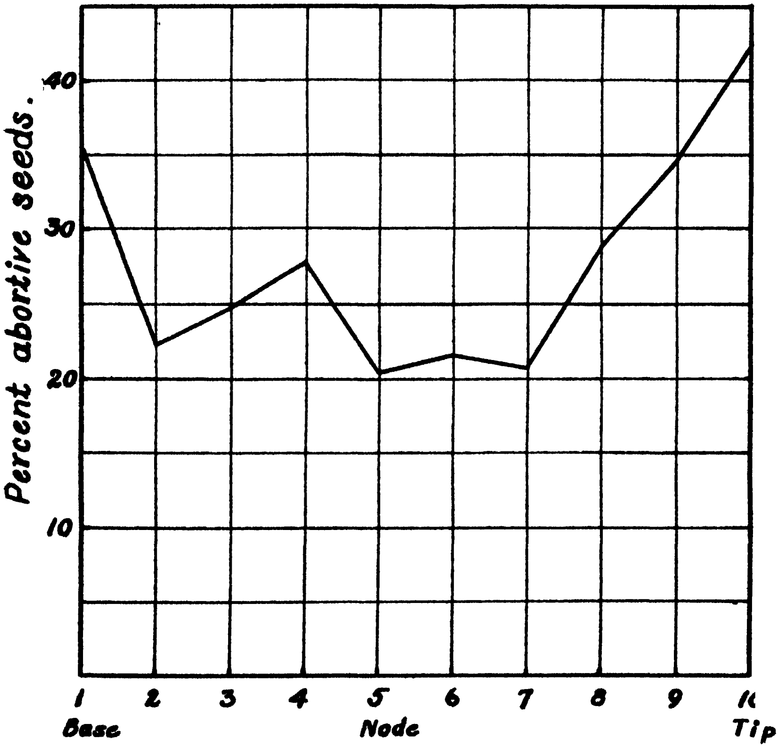

FIG. 3.—Graph showing percentage of abortive seeds at each node of main stem from base to tip of plant based on 25 Illini plants.

TABLE 6.—*Percentage of abortive seeds at different nodes of 25 Illini plants.*

Part of plant	Node	Abortive seeds %
Base	1	35.3
	2	22.2
	3	24.7
	4	27.7
Middle	5	20.3
	6	21.5
	7	20.6
	8	28.7
	9	34.5
Tip	10	42.3

Percentage of seed abortion was higher on the branches than on the main stem of these plants. The average percentage for the main stem was 27.8 and for the branches 34.4.

DISCUSSION

Abortiveness of seeds in soybeans is an important problem from the standpoint of yield. When the amount of abortion is as high as 20%, the yield of good seed is only 80% of the potential yield. But if the actual yield could be made by some means or other to equal the potential yield, that is, if all the abortive seeds could be made to develop normally, the increase would be 25% of the actual yield. Economically, therefore, the problem of abortiveness is of considerable importance.

Data presented in Table 1 indicate that there is considerable difference among varieties in percentage of abortive seeds. Such varietal differences are likely due to genetic causes, and if so, the percentage of abortive seeds is an inherited character. There is, therefore, the possibility of improving the yield of seed by reducing the percentage of abortion through selection or cross breeding.

Very little information is available on the cause of seed abortion. As stated earlier in this paper, all but the very smallest aborts examined possessed an embryo, and in those in which no embryo could be found, cotyledon tissue was extremely small or lacking altogether, indicating that growth of both embryo and cotyledons was stopped at a very early stage. In such cases, only the seed coats were stimulated and permitted to develop to any extent. Many seeds were examined in which the seed coats were extensive enough to cover a half-sized seed, but they were entirely devoid of any contents, either embryo or cotyledons. It is believed, therefore, that fertilization is accomplished in practically all cases, but that nutrition is cut off from the abortive seeds at various stages of development, thereby bringing about a considerable range in size and weight.

As shown above, certain positions in the pod and on the plant are favored over others from the standpoint of development. It would seem that the basal seed, being nearest the source of nutrition, would be the seed most likely to develop, but as shown above, it is the tip seed rather than the basal that has the better chances of development. The same principle may be concerned here as in the case of certain trees, the uppermost bud of which, rather than the lowest bud, is the one that has the advantage. On the other hand, it is the middle part of the soybean plant rather than the tip that has the lower percentage of seed abortion. Also, it is the middle seed rather than the tip in three-seeded pods that is heaviest. The development of kernels on a wheat spike shows similar relationships. At the base of the spike one or more sterile spikelets are often found, and the same is true of the tip of the spike, but usually none is found in the middle portion. Furthermore, the kernels in the middle spikelets are usually found to be the best developed of all. Hence, seed development on different parts of a soybean plant and in different portions of a soybean pod may be the particular expression of a general principle of reproductive development prevailing in plants.

There was no relation between the number of normal seeds on a plant and the percentage of seed abortion. Heavy-producing plants had high percentages as often as low percentages, indicating that the difference in abortion percentage was not due to inadequate nutrition. Additional evidence on this point is furnished by data in Table 1. If the supply of nutrition is a factor concerned with seed abortion, it would be expected that soil fertility would be important. The Illini variety was grown on poorer soil than the other strains and yet the amount of abortion (22.2%) was less than 2% greater than that of two strains (A. K. 125 and 146) grown on the more productive soil. It would seem that if the supply of nutrition is the primary factor, greater differences than these would be obtained.

With the information available at present, it is believed that the occurrence of abortive seeds in soybeans is largely a genetic problem. There may be genes responsible for abortive seeds in soybeans, just as there are genes responsible for defective seeds of various kinds and degrees in maize. However, in the absence of experimental work, it is useless to speculate except as such speculation may suggest proper methods of attack. It is hoped that investigations now in progress may throw some light on this problem.

SUMMARY

Studies on occurrence of abortive seeds in soybeans brought out the following facts:

1. The amount of abortiveness was considerable, varying for the different varieties studied from 9.4 to 22.2%. Certain varieties were significantly different in average percentages of abortion.

2. The four types of pods based upon seed number showed approximately the percentage of abortion expected, on the basis of chance.

3. Seed abortion was most frequent in the basal position, least frequent in the tip position, and intermediate in frequency in the middle position of the pod.

4. Normal seeds from pods containing no abortive seeds were heavier than normal seeds from pods containing one or more abortive seeds.

5. The middle seed or seeds in three- and four-seeded pods, none-abortive, showed the best development.

6. Seed abortion was least at the center of the plant, greatest at the tip, and intermediate in frequency at the base.

HYGROSCOPIC MOISTURE OF FLAX SEED AND WHEAT AND ITS RELATION TO COMBINE HARVESTING[1]

A. C. DILLMAN[2]

INTRODUCTION

The advent of the combined harvester-thresher in humid areas makes a study of factors affecting moisture content of grain increasingly important. This paper reports the results of experiments on the comparative rate of absorption of hygroscopic moisture by flax seeds and wheat when exposed to atmospheres of different relative humidities, and the effect of temperature on the rate of absorption. The investigation included, also, the rate of drying of moist and of wet seeds when exposed to different atmospheric humidities, and the effect of an air current (simulating a slight breeze) on the rate of drying of wet seeds. Seeds of alfalfa and corn and whole flax bolls were included in one or more of the experiments. The rate of absorption of free water by wheat at two temperatures, *viz.*, 10° and 25° C, also was determined as a matter of some interest in comparison with the absorption of hygroscopic moisture.

Anyone who has had experience in handling flax knows that it is especially difficult to thresh when wet or damp. Investigations of the moisture content of standing flax, as reported in an earlier paper (7),[3] have shown that flax seeds take up moisture rapidly during a period of high humidity. Fortunately, the reverse process, the drying of standing flax and cereals, also proceeds rapidly under favorable weather conditions.

It occurred to the writer, during the investigations referred to above, that flax seeds possibly may absorb moisture more rapidly than wheat under the same conditions of humidity. The outer layer of the seed consists of a gelatin-like substance which takes up free water rapidly. This can be seen by mixing a drop or two of water with a few seeds in the palm of the hand. A mucilage is formed at once on the seeds. This rapid absorption of moisture probably is a provision of nature to effect prompt germination in this seed of high oil content.

The term "humidity" refers to the condition of the atmosphere as regards moisture. "Absolute humidity" is defined as the actual quantity of water vapor present in a given quantity of air. It usually is expressed as grains per cubic foot of air, or as grams per cubic meter. "Relative humidity" is defined as the ratio of the actual quantity of water vapor present to the quantity the air could hold, if saturated, at that temperature. Relative humidity is expressed as percentage of saturation. The quantity of water vapor which the air can hold depends entirely on the temperature. Air saturated at 60° F becomes approximately only half saturated (relative humidity 53%) if the temperature is raised to 80° F, other conditions being the same. A further rise in temperature to 100° F will reduce the relative humidity to 29%, if there is no further addition of moisture to the air. As the temperature falls, the relative humidity increases until at the point of saturation, or the "dew point," water vapor is condensed as free water in the form of dew, fog, cloud, mist, or rain. Relative humidity deals only with water vapor, which, in general, obeys the laws of diffusion of gases.

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[1] Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication June 20, 1929.

[2] Associate Agronomist in Charge of Flax Investigations.

[3] Reference by number is to "Literature Cited," p. 74.

REVIEW OF LITERATURE

Numerous observations and experiments have been made by different investigators of the moisture changes occurring in stored grain. A review of the literature of the moisture content of corn is given by Bailey (1), who also reports the results of an experiment on the absorption of hygroscopic moisture by corn which he conducted under controlled conditions. He found that after the corn had come to equilibrium, "the mean percentages of hygroscopic moisture in the three samples studied ranged from 8.25 at 34.8% relative humidity (25° C) to 17.57 at 85.4% relative humidity." In a later publication, Bailey (2) reviews the literature dealing with the subject of moisture in stored wheat.

Coleman and Fellows (4) determined the maximum hygroscopic moisture which different cereal grains and flaxseed will absorb when exposed to atmospheres of different relative humidities. They found that the several cereals, including wheat, oats, corn, barley, rye, rice, and buckwheat, attain about the same moisture content when equilibrium has been reached in atmospheres of equal humidity. Flaxseed, probably because of its high oil content, does not absorb as much moisture as the cereals and buckwheat. The graph showing the results obtained by Coleman and Fellows is reproduced in Fig. 1. The graph is based upon the average of several determinations, including five classes of wheat, three varieties of corn, and three samples each of barley, oats, and rice. Six samples of flaxseed, Northwestern, Southwestern, Argentine, Indian, Manchurian, and fiber flax, were included. The hygroscopic moisture of flaxseed ranged from about 4.6% at a relative humidity of 15% to 27.3% in a saturated atmosphere.

Unfortunately, these investigators did not record the rate of absorption of hygroscopic moisture. The rate at which hygroscopic moisture is absorbed in a humid atmosphere and the rate at which it is evaporated in a dry atmosphere are of practical importance in connection with the rapidity of ripening and drying of standing grain, the drying of harvested grain in the windrow or shock, and the drying of stored grain in ventilated bins.

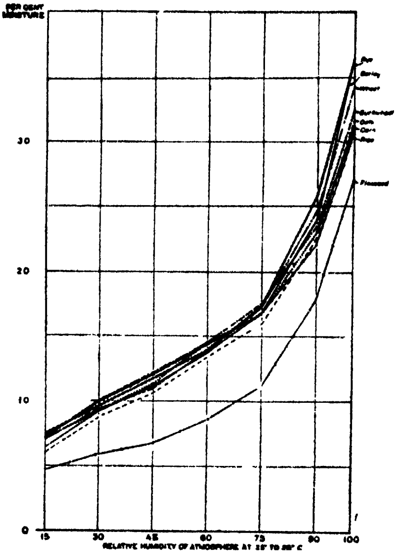

FIG. 1 —Hygroscopic moisture of cereal grains and flaxseed exposed to atmospheres of different relative humidities at 25° to 28° C. (From Coleman and Fellows.)

The earlier literature dealt almost entirely with the moisture content of threshed grain in shipment and storage. During the past two or three years, however, there have been extensive investigations of the moisture content of standing grain in relation to its condition for harvesting with the combine and for later storage. Previous to these studies, however, experienced combine operators had learned by practical experience the danger of harvesting damp grain, and the necessity of delaying harvesting, following a rain or heavy dew, until the grain was dry enough to store safely. They had learned to delay harvesting until later in the morning and to work later at night than in harvesting with a binder.

The daily variation in the moisture content of standing wheat was first pointed out by Black and Boerner (3) in studies made at Jamestown, N. Dak., in 1927. Reynoldson, *et al.* (10) found a considerable range in the moisture content of wheat threshed by combines in the northern Great Plains, the moisture content ranging from about 10 to 17%, depending upon the maturity of the grain and the previous weather conditions. Daane (5), in studies made in Oklahoma, found the moisture content of wheat threshed from standing grain to change from 1 to 3% between morning and afternoon.

In a group of papers, presented as a symposium before the American Society of Agricultural Engineers, at Chicago in December, 1928, several investigators reported the results of investigations of the moisture content of cereal grains under different conditions of harvesting, threshing, and storing. These papers were published in *Agricultural Engineering*[4] for January and February, 1929, to which the reader is referred. It is now well recognized that standing grain takes up moisture rapidly during a light rain or heavy dew and also during a period of high humidity. The rate of drying, on the other hand, must depend on several climatic factors, including the humidity of the atmosphere, the temperature, and the movement of the air, or wind velocity.

SCOPE OF EXPERIMENTS

The moisture content of standing grain evidently is constantly changing with weather conditions, especially with changes in the humidity of the atmosphere. From the farmer's standpoint the rate of drying of ripening crops, and of harvested crops, including hay, is of great practical importance.

The first experiment here reported was planned to measure the rate of absorption of hygroscopic moisture by the wheat grain, the seeds and bolls of flax, and by seeds of alfalfa, in order to determine whether there is a material difference in the rate of absorption by different seeds. Previous experience (6) had shown that whole flax bolls, including the contained seeds, are highly hygroscopic, and that the bolls open in dry air and close when wet by dew or rain.

In a second experiment the effect of temperature, or more properly the effect of vapor pressure, on the rate of absorption of hygroscopic moisture in a saturated atmosphere was determined.

The third experiment was planned to determine the rate of drying of moist and of wet seeds. Wheat, flax, and alfalfa seeds were brought to moisture contents above those which are safe for storage, and the changes in moisture content determined when the seeds were placed in atmospheres of different relative humidities. In another test, wheat and flax seeds were saturated and the moisture changes then noted as before.

In a fourth experiment the effect of an air current, simulating the effect of a slight breeze, on the rate of drying of wet seeds as compared with the rate of drying in still air was determined.

Finally, in the fifth experiment, the rate of absorption of free water by wheat at two temperatures, *viz.*, 10° and 25° C, was determined.

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[4] Agricultural Engineering, 10 (1, 2):3–80. 1929.

EXPERIMENTAL METHODS

The methods employed by the writer were similar to those used by Coleman and Fellows, except that weighings of the seed samples were made at definite intervals during the first day and daily thereafter for a period of 10 or more days.

Atmospheres having relative humidities of approximately 45, 75, 90, and 100% (saturated) were maintained in ordinary desiccators of 6-inch diameter by the use of different solutions of sulfuric acid and water. The specific gravity of each solution was determined by the use of a More-Westphal balance. After the experiments were completed the specific gravity of the solutions again was determined. No significant change in the solutions had taken place. For the convenience of anyone who may desire to carry on similar experiments, the solutions used by Coleman and Fellows and by the writer are shown in Table 1.

TABLE 1.—*Reference table for making humidity solutions of sulfuric acid and water.**

Relative humidity required %	Sulfuric acid in solution at 25°C %	Specific gravity required	For 1 liter of solution (approximate)	
			H_2SO_4 cc	Water cc
15	61.8	1.514	551	504
30	52.6	1.415	438	613
45	46.6	1.358	372	676
60	38.5	1.283	292	751
75	30.4	1.220	215	807
90	18.5	1.125	125	921

*Table computed on H_2SO_4 of specific gravity 1.832.

The temperature was maintained at about 25° C, the extreme range being from 23° to 27° C (73° to 81° F). Variations of temperature, however, within 5° or 10° C have little effect on the *relative humidity* of the air within a closed chamber, as pointed out by Wilson (11). The vapor pressure, on the other hand, varies directly with the temperature. The effect of temperature on the rate of absorption of hygroscopic moisture is discussed in a later paragraph.

In every case where the seeds were moistened in preparation for the drying experiments, they were stored at a temperature slightly above freezing for three or four days, until the moisture was well absorbed, before the experiment was begun. In wetting the flax seeds, the gelatin-like surface of the seed is altered so that its response to humidity possibly may be different from that of fresh natural seeds, although this has not been determined.

RESULTS OBTAINED

MOISTURE ABSORPTION BY DRY SEEDS

The flax bolls and seeds and the wheat used in this experiment had been stored at room temperature for a year or more, and it may be assumed that they were at equilibrium as to moisture content. At the beginning of the experiments the seeds and bolls of flax contained approximately 5% of moisture based on dry weight, whereas the alfalfa seeds contained 6%, and the wheat seeds 8%. Ten grams of each kind of seeds were placed in round aluminum trays of 2¼ inches diameter and a half inch deep, the seeds being about one-eighth inch deep in the trays. Only 5 grams of flax bolls were used in each sample, the bolls nearly filling the trays.

This experiment was conducted in duplicate, that is, a second series (B) was carried on, beginning three days after the first (A). Series B, however, was held at a more uniform temperature than Series A during the first 48 hours and the results are perhaps more significant. Only the results from Series B, therefore, are reported.

The moisture content of the flax bolls and seeds and the wheat and alfalfa seeds, based on the initial dry weight, is shown in Table 2. The rapid increase in moisture content is remarkable. In the atmosphere of 90% relative humidity the moisture content of the flax bolls increased from 5.0 to 10.1% in 8 hours and to 16.3% in 48 hours. In other words, the initial moisture content was doubled in 8 hours and more than trebled in 2 days. The moisture content of the flax seeds increased 2.6% in 8 hours and 5.5% in 24 hours. The wheat increased 2.1% in moisture in 8 hours and 5.7% in 24 hours.

The comparative rate of absorption of hygroscopic moisture is shown graphically in Fig. 2, where the increase in moisture content at intervals for 34 hours is expressed as percentages of the initial weight (10 grams) of the samples. As was expected, the flax seeds absorbed moisture somewhat more rapidly than wheat at first, and both the flax seeds and wheat absorbed moisture much more rapidly than the alfalfa seeds.

It is noteworthy that the flax bolls absorbed hygroscopic moisture approximately twice as rapidly as the flax seeds. In the saturated atmosphere the bolls gained 6.0% in 8 hours, while the seeds absorbed only 2.9% of moisture. In 24 hours the bolls absorbed 11.3% and the seeds 5.5% of moisture, based on initial weights of the samples. About the same proportions hold true in the atmospheres of 90, 75, and 45% relative humidity. This rapid absorption of hygroscopic moisture by the flax boll accounts for the fact that flax becomes tough and difficult to thresh after a brief period of high humidity.

In Fig. 3 is shown graphically the rate of absorption and moisture content, based on dry weight, of whole flax bolls and of flax seeds exposed to atmospheres of different relative humidities. It will be seen that the absorption of moisture in these comparatively dry

TABLE 2.—*The moisture content (in percentage of the initial dry weight) of flax bolls and seeds and wheat and alfalfa seeds exposed to atmospheres of different relative humidities at a temperature of about 25°C during a period of 10 days, as a measure of the rate of absorption of hygroscopic moisture.*

Material	Initial moisture content %	Moisture content after an interval of Hours 2	4	8	14	24	Days 2	3	4	5	6	7	8	9	10
Relative Humidity, 100%															
Flax bolls...	5.0	7.6	9.2	11.3	12.9	16.9	21.7	25.3	26.2	28.6	28.8	29.5*	—	—	
Flax seeds...	5.0	6.2	6.9	8.1	9.1	11.0	13.1	15.0	15.8	17.4	18.4	19.0	19.5	20.4*	
Wheat......	8.0	8.9	9.4	10.5	11.7	14.6	17.9	20.6	22.3	23.5	24.6	25.5	26.2	26.9*	
Alfalfa.....	6.0	6.4	6.6	7.0	7.3	8.1	9.2	10.7	12.0	13.1	14.4	16.4	18.7	20.4*	
Relative Humidity, 90%															
Flax bolls...	5.0	7.3	8.4	10.1	11.2	13.8	16.3	17.7	18.0	18.7	18.1	19.0*			
Flax seeds. .	5.0	6.1	6.7	7.6	8.8	10.5	12.3	13.6	14.4	14.7	15.2	15.6	16.2	16.2	16.3
Wheat......	8.0	8.8	9.3	10.1	11.3	13.7	16.8	18.8	20.0	20.6	21.0	21.7	22.1	22.2	22.3
Alfalfa.....	6.0	6.2	6.5	13.4	7.3	7.8	8.9	9.8	10.7	11.3	12.0	12.9	14.0	14.1	14.6
Relative Humidity, 75%															
Flax bolls...	5.0	6.6	7.4	8.6	9.2	10.7	11.5	11.8	11 6	11.9	11.7	11.8	11.6	11.5	11.5
Flax seeds. .	5.0	5.5	5.8	6.4	6.8	7.6	8.5	9.1	9.4	9.7	9.9	10.2	10.3	10.4	10.5
Wheat......	8.0	8.3	8.5	8.9	9.2	10.3	11.2	13.1	14.0	14.5	14.7	15.1	15.4	15.5	15.6
Alfalfa.....	6.0	6.1	6.2	6.3	6.4	6.7	7.3	7.6	7.9	8.3	8.6	8.8	9.0	9.2	9.3
Relative Humidity, 45%															
Flax bolls ..	5.0	5.6	5.9	6.4	6.6	7.1	7.1	7.2	7.1	7.1	7.2	7.2	7.2	7.2	7.2
Flax seeds...	5.0	5.3	5.5	5.7	5.9	6.3	6.5	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Wheat. . ..	8.0	8.1	8.2	8.3	8.5	8.8	9.3	9.6	9.7	9.8	9.8	10.0	10.0	10.0	10.0
Alfalfa.....	6.0	6.1	6.1	6.2	6.2	6.3	6.5	6.5	6.6	6.6	6.6	6.6	6.7	6.7	6.7

*Mold appearing.

seeds and bolls was very rapid during the first day, the rate of absorption slowing down more or less consistently as the time of ex-

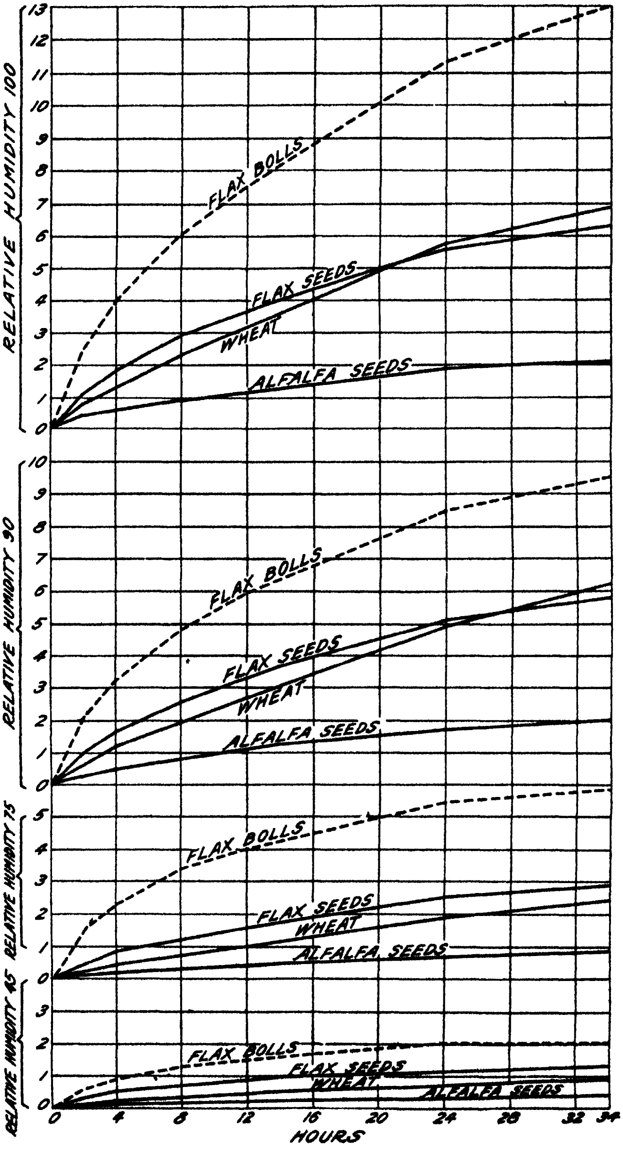

FIG. 2.—Showing the increase in moisture content of whole flax bolls and of seeds of flax, wheat, and alfalfa in percentages of original weight (10 grams), when exposed to atmospheres of 45, 75, 90, and 100% (saturated) relative humidities at a temperature of about 25° C during a period of 34 hours.

posure was extended. In an atmosphere of 90% relative humidity the flax seeds absorbed 5.5% of moisture in the first 24 hours. The moisture content then had reached 10.5%, which is about the upper limit for safe storage of flaxseed. The same seeds gained 1.8% in the second day, 1.3% in the third day, 0.8% in the fourth day, and 0.5% in the fifth day. In an atmosphere of 75% relative humidity, the absorption of moisture was approximately only half as rapid as at 90% relative humidity. At 75% relative humidity the seeds contained 10.4% of moisture and the bolls nearly 12.0% at the end of 8 days exposure. This probably is near the maximum moisture content at which flax can be threshed and the seed stored without damage.

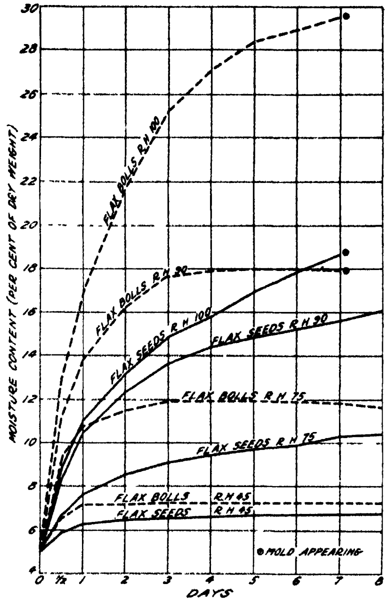

FIG. 3.—Showing rate of absorption and moisture content, based on dry weight, of whole flax bolls and of flax seeds exposed to atmospheres of relative humidities of 45, 75, 90, and 100% (saturated) at a temperature of about 25° C for a period of 8 days.

EFFECT OF TEMPERATURE ON RATE OF ABSORPTION OF HYGROSCOPIC MOISTURE

In order to determine the effect of temperature on the rate of absorption of hygroscopic moisture, 10-gram samples of Marquis wheat and of flax seeds were placed in desiccators in saturated atmospheres and exposed to different temperatures. One desiccator was held at room temperature, about 25° C, and the other placed outside on the windowledge where the temperature ranged from 2° to 15° C. The initial moisture content of the wheat, based on dry weight, was approximately 8% and that of the flax 5%. The trays were weighed at the end of 12 and of 24 hours exposure and daily thereafter. The samples were not weighed from the 9th to the 15th day inclusive, but weighing was resumed on the 16th day. At the end of the 20th day the samples which previously had been held at room temperature were placed in the dessiccator outside. The moisture content of the samples, at intervals for 28 days, is shown graphically in Fig. 4.

At room temperature, the wheat and flax absorbed moisture more rapidly and reached a much higher final moisture content than at the lower temperature. At the end of 24 hours the moisture content of the wheat was approximately 18% at room temperature and 13% at the lower temperature. By the end of the 8th day the wheat exposed at the lower temperature had reached a moisture content of 25.5% and remained more or less constant thereafter. The wheat exposed at room temperature finally came to equilibrium (18th to 20th days) at a moisture content of nearly 44%. The flax came to equilibrium at about 16% at the lower temperature and at about 32% at the higher temperature.

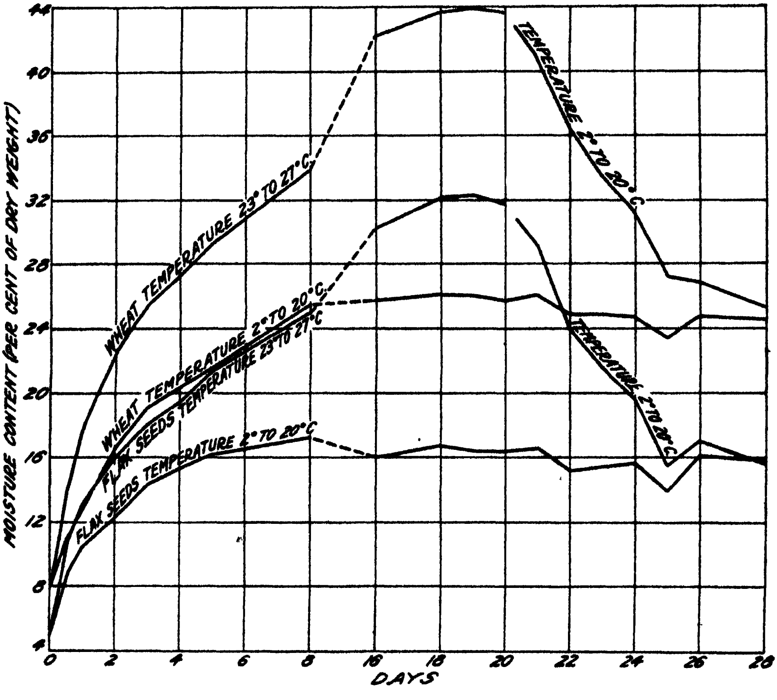

FIG. 4.—Showing the rate of absorption of hygroscopic moisture by wheat and flax seeds in saturated atmospheres at room temperatures (23 to 27° C) and at outside temperature (from near 2° C to 20° C) during a period of 20 days. At the end of 20 days the trays formerly held at room temperature were placed in the chamber outside. The moisture content of these samples dropped rapidly for a period of 5 days to the end of the 25th day. At the end of the 28th day the flax seeds were at equilibrium and the wheat seeds nearly so.

At the end of the 20th day, as mentioned above, the samples previously held at room temperature were placed in the desiccator outside. At the lower temperature they lost moisture rapidly. In five days (end of the 25th day), the sample of wheat lost 16.3% of moisture and the flax seeds exactly the same. All samples were practically at equilibrium at the end of the 28th day, when the flax contained nearly 16% and the wheat approximately 25% of moisture.

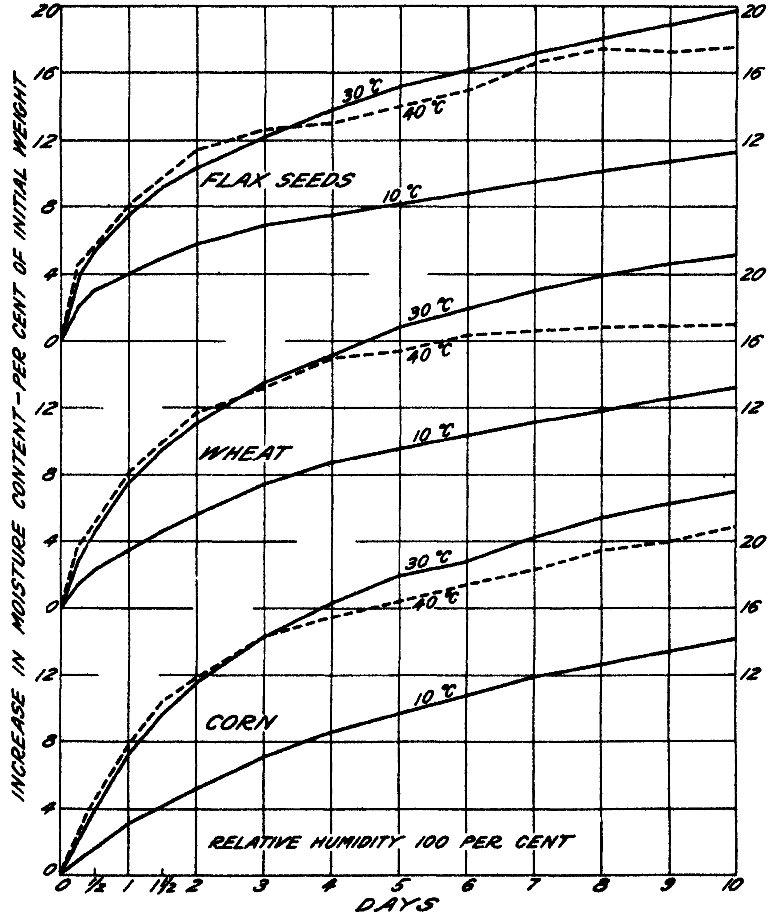

FIG. 5.—Showing increase in moisture content, based on initial weight of 10 grams, of flax, wheat, and corn seeds exposed to saturated atmospheres at 10°, 30°, and 40° C for a period of 10 days. The initial moisture content of the flax was 5.1%, of the wheat 9.7%, and of the corn 6.9%.

Another experiment was conducted in which seeds of flax, Marquis wheat, and yellow dent corn were exposed to saturated air in desiccators at controlled temperatures of 10°, 30°, and 40°C. The samples were weighed at the end of 6, 12, 24, 36, and 48 hours, and daily thereafter. The initial moisture content of the flax was 5.1%, of the wheat 9.7%, and of the corn 6.9%, based on the initial weight (10 grams) of the samples. The absorption of hygroscopic moisture, expressed as a percentage of the initial weight, is shown graphically in Fig. 5.

The rate of absorption of hygroscopic moisture was approximately twice as rapid at 30° C as it was at 10° C. The ratio was somewhat less than this for the flax and somewhat higher in corn during the first 48 hours. As the time of exposure extended beyond 24 hours, the ratio narrowed somewhat. This is shown in Table 3 where the percentages of moisture absorbed at the two temperatures are expressed as ratios.

TABLE 3.—*The comparative rates of absorption of hygroscopic moisture by seeds of flax, wheat, and corn at 10° and 30°C, expressed as percentages where the moisture absorbed at 10°C is taken as 100.*

Period of exposure	Ratio of absorption, $\frac{\text{absorption at 30°C}}{\text{absorption at 10°C}}$			
	Flax	Wheat	Corn	Average
6 hours	188	199	213	200
12 hours	180	197	238	205
24 hours	186	213	233	211
36 hours	184	204	229	206
2 days	179	196	221	199
3 days	177	181	200	186
4 days	180	173	189	181
5 days	184	177	186	182
6 days	182	174	173	176
7 days	179	172	171	174
8 days	178	169	170	172
9 days	176	164	166	169
10 days	174	160	162	165

It is notable that the rate of absorption of hygroscopic moisture was approximately the same at 40° as at 30° C (Fig. 5) during the first three days, after which absorption was slower at 40°. This was true of all three grains. It is known that a high temperature inhibits enzyme activity in the process of germination of seeds. As the absorption of moisture is the initial process in the germination of seeds, it is likely that absorption is determined to some extent by enzyme activity, which in turn is influenced by temperature. The rate of absorption of hygroscopic moisture is determined not alone by the relative humidity and other physical factors, but by the functions of the seeds themselves.

It is very evident that the rate of absorption of hygroscopic moisture by seeds does not depend alone upon the relative humidity, but to a large degree upon the temperature to which the grain is exposed. The absolute humidity and vapor pressure of the atmosphere vary directly with the temperature. According to the psychrometric tables prepared by Marvin (9) of the U. S. Weather Bureau, the vapor pressure of a saturated atmosphere is equal to 1.241 inches of mercury at a temperature of 30° C (86° F) and to 0.360 inch at 10° C (50° F). In other words, the vapor pressure and the quantity of moisture contained in a saturated atmosphere are more than three times as great at 30° C as at 10° C. The results obtained by the writer show that the vapor pressure has a marked effect on the rate of absorption of hygroscopic moisture.

The close relation between the temperature and the absolute humidity is seen by reference to Fig. 6, where the mean monthly temperature, the absolute humidity, and the relative humidity at Bismarck, N. Dak., are shown. The mean monthly relative humidity is comparatively constant throughout the year, whereas the absolute humidity is low during the winter months and reaches a maximum in midsummer. The low absolute humidity at low temperatures must have an important bearing on the rate of drying of ear corn and of other cereals during the winter months. The common observation that "corn freezes dry" has a sound scientific basis.

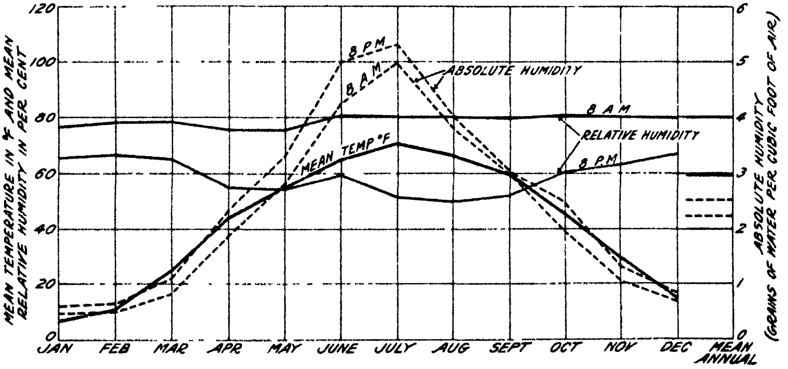

FIG. 6.—Showing the relation between the mean monthly temperature and the absolute humidity, and the comparatively constant relative humidity (mean monthly) at Bismarck, N. Dak., for a period of 43 years. (Drawn from published data of the U. S. Weather Bureau.)

CHANGE IN MOISTURE CONTENT OF MOIST AND OF WET SEEDS EXPOSED TO ATMOSPHERES OF DIFFERENT RELATIVE HUMIDITIES

After observing the comparatively rapid rate of absorption of hygroscopic moisture by dry seeds, the question naturally arose as to what would be the effect of exposing moist or wet seeds to atmospheres of different relative humidities. Accordingly, wheat, flax, and alfalfa seeds were brought to moisture contents well above those which are safe for storage. Ten-gram samples then were exposed in the desiccators as in the preceding experiment. In order to complete the range of relative humidities, two desiccators were added in which the seeds were exposed above sulfuric acid. As sulfuric acid has a great affinity for moisture, this should produce an atmosphere of nearly zero relative humidity.

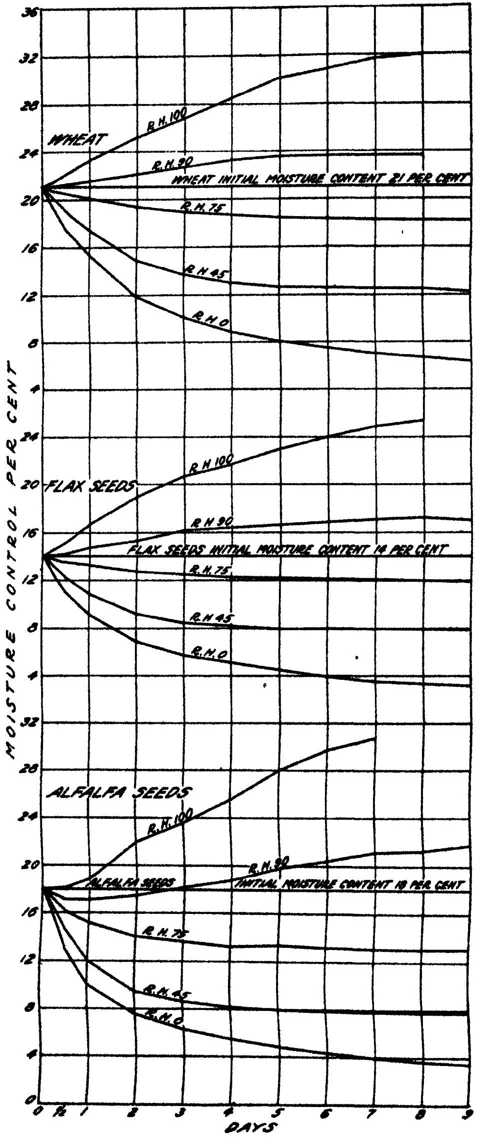

FIG. 7.—Showing the rate of change in moisture content, based on dry weight, of wheat, flax, and alfalfa seeds of moderately high initial moisture content when exposed to atmospheres of different relative humidities at a temperature of about 25° C.

The rate of change in these seeds of moderately high initial moisture content, when exposed to atmospherees of different relative humidities, is shown in Fig. 7. The initial moisture content of the wheat was approximately 21%; of the flax, 14%; and of the alfalfa, 18%. At this initial moisture content both the wheat and flax took up moisture in atmospheres of 90 and 100% (saturated) relative humidity. In an atmosphere of 75% relative humidity they lost moisture slowly and at 45% relative humidity they lost moisture rapidly. Similar changes occurred in the alfalfa seeds.

Another experiment was carried on in which wheat and flax seeds were moistened to a point of approximate saturation and then exposed to atmospheres of different relative humidities. The initial moisture content of the wheat was 38.0% and of the flax 25.0%, based on dry weight. The rate of change in moisture content is shown graphically in Fig. 8.

It will be seen that the flax still took up moisture when exposed to a saturated atmosphere, gaining approximately 5% in moisture content during a period of 7 days. The wheat at first lost moisture, but after 12 hours gained slowly. This early loss of moisture by the wheat probably was due to diffusion to the relatively drier flax seeds which were exposed in a separate tray in the same desiccator.

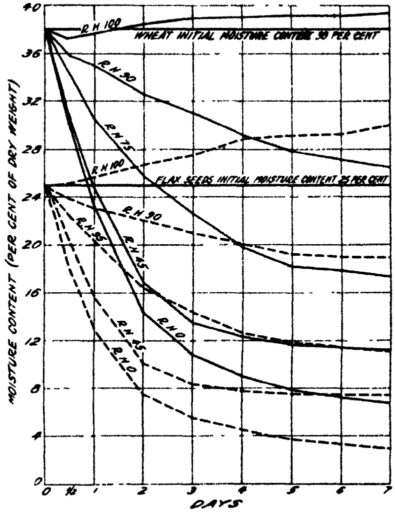

FIG. 8.—Showing the rate of change in moisture content, based on dry weight, of wheat and flax seeds of high initial moisture content when exposed to atmospheres of different relative humidities at a temperature of about 25°C.

In atmospheres of 90%, 75%, 45%, and zero relative humidity, both the wheat and flax lost moisture in proportion to the dryness of the atmosphere. In the atmosphere of 45% relative humidity the wheat lost 5.3% of moisture in 8 hours, 7.6% in 12 hours, 13.3% in 24 hours, and 21.2% in 48 hours. The loss of moisture at 45% relative humidity was approximately twice as rapid as at 75% relative humidity and nearly four times as rapid as at 90% relative humidity.

EFFECT OF AN AIR CURRENT ON RATE OF DRYING

In the experiments reported above the seeds were exposed to atmospheres of different relative humidities in a closed container, that is, in still air. Under such conditions the rate of drying is dependent on the rate of diffusion from the surface of the wet seeds to the drier air. It is believed that, in still air, a layer of super-moistened air is formed, closely surrounding the seeds, which prevents the rapid diffusion of moisture to the drier air at some distance from the seeds. If this super-moistened layer of air is removed by an air current or breeze as rapidly as formed, the rate of drying will be more rapid.

An experiment was planned, therefore, to determine the rate of drying of wet seeds in an air current. A solution of sulfuric acid and water of such proportions as to produce an atmosphere of 45% relative humidity was placed in two flasks through which air was drawn by suction. A flask containing glass wool was placed in the train to absorb any particles of liquid which might be drawn through. The grain was exposed in a 1-inch U-tube. The set up of this apparatus is shown in Fig. 9.

A solution to produce a relative humidity of 45% was chosen because this was about the humidity of the laboratory and, therefore, only a slight change would be made in the humidity of the air in passing through the solution. The temperature was held nearly constant at 25° C. The initial specific gravity of the solution was 1.350. At the termination of the experiments the specific gravity of the solution in flask A was 1.389 and that of flask B was 1.350. This indicates that the stream of air had taken up a trace of water vapor from the solution in flask A.

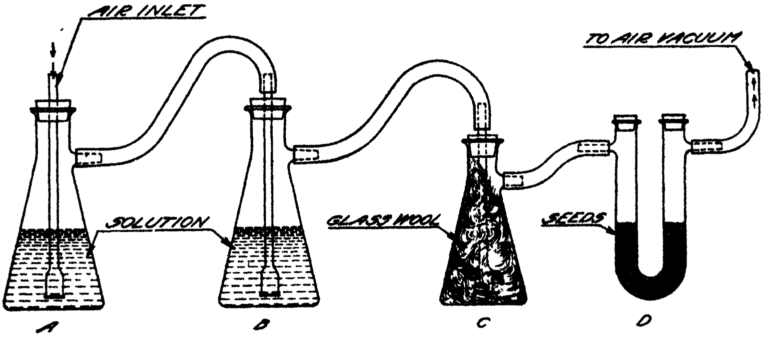

FIG. 9.—Set-up of drying apparatus. The two suction flasks (A and B) contained a solution of sulfuric acid and water proportioned to produce a relative humidity of 45% in the air drawn through the tube. The flask C contained glass wool to absorb any particles of the liquid which might escape from flask B. The 1-inch U-tube (D) containing the seeds was connected to a vacuum pump. About 500 cc of air per minute were passed through the train.

Two samples of wheat which had an initial moisture content of 38.6%, based on dry weight, and one sample of flax of 25.4% initial moisture content were exposed separately to the air current. The results are shown graphically in Fig. 10.

The rate of drying was nearly twice as rapid in the air current as in still air. The wheat lost 5.3% of moisture in still air and 13.0% in the air current during a period of 8 hours, or at the ratio of 1 : 2.45. For the flax seeds the ratio of loss of moisture in still air versus the air current was 1 :1.91 during a period of 8 hours. The ratios were narrowed as the time of exposure was lengthened.

The effect of a breeze or wind on the rate of drying of standing grain must be very marked, providing the relative humidity of the air is low enough to allow drying to proceed. The wheat head or the flax boll, exposed on all surfaces to the action of wind, is in ideal position to dry rapidly. In his recent book, "Physics of the Air," Humphreys (8), in discussing the several factors which affect evaporation, says—"*C. Velocity of the Wind.*—All observers agree that evaporation increases with wind velocity, presumably through increase, by the action of eddy diffusion, of the vapor pressure gradient near the surface. As above explained, it is now known that in the case of a strictly horizontal and steady wind, evaporation from an area of medium size is proportional to the square root of the wind velocity. But, in general, these conditions are not fulfilled in nature. The wind usually has a variable vertical component, and, besides, is irregular in strength and direction. There is not, therefore, any constant relation of evaporation to the average horizontal component of wind velocity—the value usually measured."

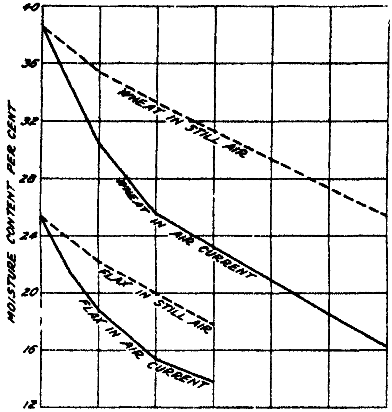

FIG. 10—Showing the comparative rate of drying of 10-gram samples of wet wheat and flax seeds (initial moisture contents of 38.6% and 25.4%, respectively, based on dry weight) in air and in an air draft (500 cc per minute drawn through the U-tube containing the seeds) in atmospheres of approximately 45% relative humidity at a temperature of about 25° C.

RATE OF ABSORPTION OF FREE WATER BY WHEAT SEEDS

The absorption of free water by standing grain during a rain must be extremely rapid as compared with the absorption of hygroscopic moisture in a saturated atmosphere. In order to determine the rapidity of water absorption by wheat seeds, an experiment was conducted in which a quantity of wheat was submerged in water, and samples removed, weighed, and the moisture determined at definite intervals. Wheat was chosen instead of flax as the latter is difficult to handle when wet because of the mucilaginous layer on the seed coat.

About 500 grams of plump, air-dry, Marquis wheat were placed in a large beaker and covered with distilled water, both the water and grain being at the same temperature. At the end of exactly 2½ minutes a sample of about 12 grams was removed, quickly drained in a wire strainer, then rolled between the folds of a dry towel, and finally rubbed between dry blotters for half a minute. The grain then was transferred to a closed aluminum tray and weighed at once.

Similar samples were taken at the end of 5, 10, 20, 30, and 60 minutes, and at longer intervals thereafter up to 24 hours, and finally at the end of 48 hours.

The time required to transfer the sample from the beaker to the tray was just 1 minute, which included a half minute for rolling the grain between the dry blotting papers. All samples were treated alike, and close observation showed that all free surface water was removed. The experiment was conducted at two temperatures, *viz.*, 10° and 25° C. The samples were dried for 72 hours at 99° C in a vacuum oven of about 5 pounds pressure.

The moisture content of the grain, based on dry weight, the percentage of moisture absorbed at each temperature, the difference in absorption at the two temperatures, and the ratio of gain is shown in Table 4.

TABLE 4.—*The rate of absorption of free water by wheat seeds at temperatures of 10° and 25° C at intervals from 2½ minutes up to 48 hours.*

Interval	Moisture content at		Gain from initial moisture content			Ratio: $\frac{\text{gain at 25°C}}{\text{gain at 10°C}}$
	10°C	25°C	10°C	25°C	Difference	
	%	%	%	%	%	
Initial sample	11.9*	10.8	—	—	—	—
2½ minutes	16.8	16.7	4.9	5.9	1.0	1.20
5 minutes	18.2	17.8	6.3	7.0	0.7	1.11
10 minutes	18.8	19.8	6.9	9.0	2.1	1.30
20 minutes	20.3	21.5	8.4	10.7	2.3	1.27
30 minutes	21.6	23.7	9.7	12.9	3.2	1.33
60 minutes	24.0	27.5	12.1	16.7	4.6	1.38
2 hours	27.9	34.4	16.0	23.6	7.6	1.47
3 hours	31.6	38.4	19.7	27.6	7.9	1.40
4 hours	34.2	42.5	22.3	31.7	9.4	1.42
6 hours	38.5	49.7	26.6	38.9	12.3	1.46
8 hours	43.4	54.7	31.5	43.9	12.4	1.39
10 hours	—	59.5	—	48.7	—	—
22 hours	—	69.9	—	59.1	—	—
24 hours	59.2	71.2	47.3	60.4	13.1	1.28
48 hours	70.2	81.9	58.3	71.1	12.8	1.22

*This sample of wheat was held at 10°C for 16 hours in a damp refrigerator where it absorbed some moisture as compared with the sample used at 25°C.

It will be seen that the absorption of free water by wheat is very rapid. At 25° C the wheat, which had an initial moisture content of 10.8%, contained 17.8% of moisture after 5 minutes, 19.8% after 10 minutes, 23.7% after 30 minutes, and 27.5% after 1 hour. At 10° C the wheat absorbed 12.1% of moisture in 1 hour as compared with 16.7% at 25° C.

Under field conditions the absorption of water by standing wheat probably is not as rapid as in this experiment, although it is not uncommon to find wheat containing from 20 to 40% of moisture, based on dry weight, a few hours after a moderate rain.

MOISTURE CONTENT OF GRAIN IN RELATION TO COMBINE HARVESTING

The moisture content probably is the most important single factor influencing the grade and condition of harvested grain. A knowledge of the climatic factors which determine the changes in the moisture content of standing grain is of importance, therefore, especially in connection with combine harvesting. It is hardly necessary to mention that moisture is absorbed in two forms, first, as free water, in the form of rain, dew, mist, or fog; and second, as hygroscopic moisture, or moisture which is present in the air in the form of water vapor. The absorption of free water by standing grain is extremely rapid as compared with the absorption of hygroscopic moisture. In case of continuous rain, the moisture content of ripe wheat may reach 25% in a few hours, whereas it would require several days for it to reach that moisture content in a saturated atmosphere.

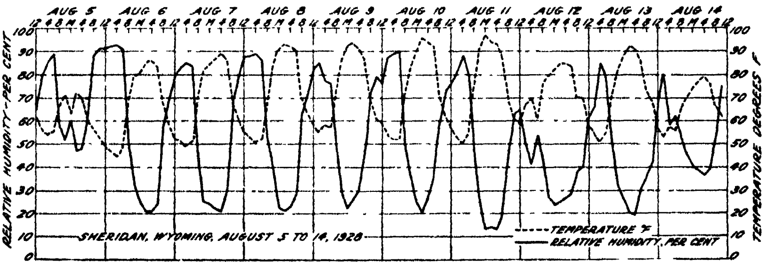

FIG. 11.—Showing the daily range in relative humidity during a 10-day period, August 5 to 14, 1928, at Sheridan, Wyo. This, probably, is typical of a comparatively dry harvest period in the northern Great Plains area.

The rate of absorption of hygroscopic moisture by standing grain evidently depends upon several factors, of which the relative humidity, temperature, wind velocity, and initial moisture content of the grain appear to be the most important.

The relative humidity varies greatly from time to time, usually being high at night and low at midday. The range in relative humidity determined at 2-hour intervals for a period of 10 days at Sheridan, Wyo., from August 5 to 14, 1928, is shown in Fig. 11. It will be seen that the relative humidity reached or exceeded 80% in nearly every night and dropped to 40% or lower during midday of 9 of the 10 days. In more humid climates the relative humidity usually reaches

90 to 100% at night, and the formation of dew is of common occurrence. When the humidity exceeds 90%, dry grain takes up moisture rapidly as shown in Figs. 2 and 3. In commercial grading the moisture content of grain is based on the wet weight. In Table 5 is shown the moisture content, based on wet weight, of flax and wheat seeds exposed to atmospheres of different relative humidities and determined at intervals up to 10 days.

At relative humidities of 45 and 75% the absorption of moisture is comparatively slow (Table 5, columns 2, 3, 6, and 7). Dry grain probably would never get out of condition in an atmosphere of 45% relative humidity, and it would rarely do so in an atmosphere of 75% relative humidity.

TABLE 5.—*Moisture content (based on wet weight) of flax and wheat seeds exposed to atmospheres of 45, 75, 90 and 100% relative humidities at a temperature of about 25° C (77° F) at intervals during a period of 10 days.*

Duration of exposure	Moisture content of seeds of Flax at relative humidity 45 %	75 %	90 %	100 %	Wheat at relative humidity 45 %	75 %	90 %	100 %
At beginning	4.8	4.8	4.8	4.8	7.4	7.4	7.4	7.4
2 hours	5.0	5.2	5.7	5.8	7.5	7.7	8.1	8.2
4 hours	5.2	5.5	6.3	6.5	7.6	7.8	8.5	8.6
8 hours	5.4	6.0	7.1	7.5	7.7	8.2	9.2	9.5
14 hours	5.6	6.4	8.1	8.3	7.8	8.4	10.1	10.5
24 hours	5.9	7.1	9.5	9.9	8.1	9.3	11.9	12.7
48 hours	6.1	7.8	11.0	11.6	8.5	10.0	14.4	15.2
3 days	6.2	8.5	12.0	13.0	8.7	11.6	15.8	17.1
4 days	6.3	8.6	12.6	13.6	8.8	12.3	16.7	18.2
5 days	6.3	8.8	12.8	14.8	8.9	12.7	17.1	19.0
6 days	6.3	9.0	13.2	15.5	8.9	12.9	17.4	19.7
7 days	6.3	9.3	13.5	16.0	9.1	13.1	17.8	20.0
8 days	6.3	9.3	13.9	16.3	9.1	13.3	18.1	20.8
9 days	6.3	9.4	14.0	16.9*	9.1	13.4	18.2	21.2*
10 days	6.3	9.5	14.0	—	9.1	13.5	18.3	—

*Mold appearing.

In atmospheres of 90 and 100% relative humidity, moisture is absorbed more rapidly. At 90% relative humidity the moisture content of the seeds of flax increased 4.7%, from 4.8 to 9.5%, in 24 hours (Table 5, column 4). During the second period of 24 hours it increased only 1.5%, or from 9.5 to 11.0%. Absorption was somewhat more rapid in a saturated atmosphere, the flaxseed absorbing 5.1% of moisture during the first 24-hour period and 1.7% during the second 24-hour period, when it contained 11.6% of moisture (column 5).

Wheat seeds, at 90% relative humidity, absorbed 4.5% in 24 hours, the moisture increasing from 7.4 to 11.9%. During the second 24-hour period it increased 2.5%, or from 11.9 to 14.4%. At 100% relative humidity wheat absorbed 5.3% of moisture during the first

24 hours, and 2.5% during the second 24-hour period, when, at the end of two days, it contained 15.2% of moisture.

These results suggest two significant conclusions: First, if the moisture content of standing grain is well below the point where it is safe for storage, it will not be increased to the danger point during a few hours of high humidity; and second, if, on the other hand, standing grain is only barely dry enough to harvest, it may become too wet for safe storage during a few hours of high humidity.

As shown in Fig. 3, flax bolls absorb hygroscopic moisture nearly twice as rapidly as do flax seeds. The rate of absorption of wheat heads has not been determined, but it is probable that a similar condition prevails. It is well known that standing flax soon becomes hard to thresh when the humidity increases, as on a cloudy day or in the evening after sundown. The same is true of wheat, but perhaps to a lesser degree.

It will be seen by reference to Figs. 2 and 3 and to Table 5 that the rate of absorption decreases as the moisture content increases. The curves, therefore, are more or less parabolic in form, absorption becoming very slow as the seeds approach the moisture equilibrium.

It is considered that flax seed is safe for storage when it contains not more than 10.5% of moisture and that wheat is safe for storage at about 14%. The samples of flax exposed at 90 and at 100% relative humidity (Table 5, columns 4 and 5) contained 9.5 and 9.9% of moisture, respectively, at the end of 24 hours, but contained 11 and 11.6%, respectively, at the end of 48 hours. At these latter moisture contents flax seed is hardly safe for storage. The samples of wheat exposed at 90% relative humidity (Table 5, column 8) absorbed 2.5% of moisture during the second 24-hour period, when, at the end of 48 hours, it contained 14.4% of moisture. At 100% relative humidity wheat contained 15.2% of moisture at the end of 48 hours. At both 90 and 100% relative humidity wheat absorbed 2.5% of moisture during the second 24-hour period, or at the rate of about 0.1% per hour. During the first 24-hour period the wheat of low initial moisture content (7.4%) absorbed about 0.2% of moisture per hour.

The rate of drying of wet grain probably is of more practical importance in relation to harvesting than the rate of absorption of hygroscopic moisture. The experiments reported here indicate that moderately moist grain will dry in an atmosphere of low relative humidity, but will absorb still more moisture in an atmosphere of high relative humidity (Fig. 7). The diffusion of moisture into or out of the grain depends, therefore, upon the relative humidity of the air and upon the actual moisture content of the grain.

The rate of drying of wet grain is at first very rapid in an atmosphere of low relative humidity (45%), and less rapid at 75% relative humidity, the rate slowing up as the grain dries (Fig. 8). The curves. therefore are in general hyperbolic in form.

Air movement increases the rate of drying. In the experiment reported (Fig 10), a current of air of 45% relative humidity approximately doubled the rate of drying of wet flax and wheat seeds as compared with still air of the same humidity. According to Humphreys (8), evaporation under ideal conditions is proportional to the square root of the wind velocity. If this holds true for wet grain standing in the field, the rate of drying would be twice as rapid in a breeze of four miles per hour and four times as rapid in a 16-mile wind as it is in a light breeze of one mile per hour.

SUMMARY

This paper reports the results of experiments on the rate of absorption of hygroscopic moisture by seeds of flax and wheat exposed to atmospheres of different relative humidities, the rate of drying of wet seeds, the effect of an air current on the rate of drying, and the rate of absorption of free water by wheat. The absorption and loss of moisture by standing grain is of particular significance in relation to combine harvesting.

Coleman and Fellows have shown that the final moisture content of the seeds of cereals and flax varies greatly when exposed for a long period (30 days or more) to atmospheres of different relative humidities (Fig. 1).

Dry flax seeds absorb hygroscopic moisture somewhat more rapidly at first than wheat seeds (Fig. 2), and both flax and wheat seeds absorb moisture much more rapidly than do alfalfa seeds. Whole flax bolls absorb moisture approximately twice as rapidly as do the seeds (Fig. 3). The rapid absorption of hygroscopic moisture by the bolls probably explains why dry flax becomes difficult to thresh after a short period of high humidity.

The rate of absorption of hygroscopic moisture by dry seeds (flax, wheat, and corn) varies with the temperature, at least within a certain range of temperature (Fig. 4). The rate of absorption is approximately twice as rapid at 30° C as it is at 10° C (Fig. 5). At 40° C the rate of absorption is about the same as at 30° C for a time, but later becomes slower, probably because the high temperature affects adversely the enzyme activity of the seeds.

Wheat seeds containing 21% of moisture, based on dry weight, and flax seeds containing 14% will either absorb more moisture or lose moisture, depending upon the humidity of the air to which they are exposed (Fig. 7). In an atmosphere of 90% relative humidity such seeds absorbed moisture slowly, whereas at 75% relative humidity they lost moisture slowly. According to Coleman and Fellows (4), wheat will come to equilibrium at 17 to 18% of moisture and flax seeds at about 11.5% in an atmosphere of 75% relative humidity. The same results were obtained by the writer.

Seeds of wheat of 38% and flax of 25% moisture content still absorbed moisture in a saturated atmosphere, but lost moisture in an atmosphere of lower relative humidity (Fig. 8). The seeds lost moisture rapidly in an atmosphere of 45% relative humidity. The curves are hyperbolic in form, flattening out as the moisture content approaches equilibrium.

At 75% relative humidity the rate of drying of wheat was comparatively slow below 18% of moisture. The moisture content was reduced only 1%, that is, from 18.2 to 17.2%, from the 5th to the 7th days. This moisture content of 17.2%, based on dry weight, is equivalent to 14.7% based on wet weight, and the sample, therefore, was still too wet for safe storage. It is evident, therefore, that a relative humidity lower than 75% is necessary to insure the rapid drying of wet grain.

An air current of about 500 cc per minute drawn through a U-tube containing wet wheat and flax seeds approximately doubled the rate of drying during a period of 8 hours, as compared with still air in a desiccator, both of 45% relative humidity.

The absorption of free water by wheat is extremely rapid as compared with the absorption of hygroscopic moisture. The absorption of water at 25° C is about 20 to 45% more rapid than at 10° C (Table 4).

The experiments reported indicate the significance of humidity in relation to the moisture content of grain which is freely exposed to the air. The results suggest a few points of practical importance, as follows:

1. It is certain that wet grain will not dry in an atmosphere of high relative humidity.
2. A relative humidity well below 75% appears to be necessary for effective drying.
3. Movement of the air, as by a breeze or wind, increases the rate of drying, provided, however, that the relative humidity is low enough to permit drying.
4. In air of high relative humidity dry grain will absorb moisture, the rate of absorption depending upon the moisture content of the grain as well as upon the relative humidity.

5. When the relative humidity is high, as at night and during humid days, it would seem desirable to close the ventilators of ventilated bins containing grain of moderate moisture content.

6. The experiments suggest the significance of relative humidity in relation to other farm operations, especially the drying of hay and the curing of tobacco.

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EFFECT OF SIZE OF SEED USED IN COMMERCIAL PLANTING ON THE INCIDENCE OF LEAF-ROLL AND MOSAIC IN POTATOES[1]

O. BUTLER[2]

When seed potatoes are sorted for market the producer obtains four grades. There are potatoes below 1½ inches in diameter, between 1½ and 1¾ inches, above 1¾ inches but not over 12 ounces in weight, and potatoes weighing more than 12 ounces. The potatoes below 1½ inches in diameter, commonly called "pig" potatoes, have a certain local sales value as fowl or animal food; those from 1½ to 1¾ inches in diameter, commonly called "seconds," are used as seed; those from 1¾ inches in diameter to 12 ounces in weight constitute the standard size seed potato of commerce; while potatoes weighing more than 12 ounces have a market value as table stock and may also be used as seed.

The greatest bulk of the gross yield of potatoes falls within the limits of 1½ inches in diameter to 12 ounces in weight, and therefore, the seed producers are more especially desirous of marketing all of their crop that falls within this size range that would prove satisfactory for seed purposes. Certified seed ranging in size from 1¾ inches in diameter to 12 ounces in weight is a standard market product, but stock ranging in size from 1½ to 1¾ inches in diameter has not an established market value. But is the latter grade less suitable for use as seed stock than the standard grade? It has been shown[3] that whole seed behaves in all respects like cut seed of similar weight, and all things being equal, is just as productive.

There remains, however, the question of the amount of degeneration diseases present in fields grown from certified standard seed and small seed from the same field. It has generally been assumed that the percentage of degeneration diseases would be higher in fields grown from small seed potatoes than in those in which standard size stock was used, and that the employment of small seed was undesirable on this ground. Since the question is an important one, especially from the point of view of the certified seed grower, we thought it would be desirable to determine just what the percentage of mosaic and leaf-roll would be in small seed and standard size seed obtained from the same source.

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[1] Contribution from Department of Botany, New Hampshire Agricultural Experiment Station, Durham, N. H. Received for publication June 17, 1929.

[2] Botanist.

[3] STUART, W., *et al.* Size of potato sets: Comparison of whole and cut seed. U. S. D. A. Bul. 1248. 1924.

The certified seed used was purchased from various growers and was always planted in adjoining rows in the same field. In some cases the seconds were planted whole, in other cases the larger tubers of this grade were cut in half along the major axis and only the smaller tubers planted whole.

The results obtained are summarized in Table 1 and show that seconds constitute just as good seed as firsts. In the case of mosaic, the fluctuations shown are small and unimportant, but in the case of leaf-roll, the more important of the two diseases, it will be noticed that, while in five-ninths of the experiments the percentage found was less in the small seed than in the large, in four-ninths of the tests it was distinctly higher. This large increase in the percentage of leaf-roll in the plants originating from small seed occurred, with one exception, when the firsts were affected with net-necrosis in substantial amounts and constituted seed of questionable quality.

TABLE 1.—*Effect of size of seed stock used on the percentage of mosaic and leaf-roll developing in the field.*

Source and kind of seed	Mosaic %	Leaf-roll %	Total disease %
	Experiment A, 1923		
W stock, firsts	0.00	2.50	2.50
W stock, seconds	0.00	0.50	0.50
	Experiment B, 1925		
D stock, firsts	3.61	1.11	4.72
D stock, seconds	2.11	0.52	2.63
H stock, firsts	0.00	10.13	10.13
H stock, seconds	0.00	6.53	6.53
R. J., firsts	0.62	3.40	4.02
R. J., seconds	0.90	2.42	3.32
	Experiment C, 1926		
D stock, firsts*	1.10	7.49	8.59
D stock, seconds*	0.21	12.07	12.28
C stock, firsts	0.00	0.50	0.50
C stock, seconds	0.43	0.87	1.30
W stock, firsts	2.18	1.50	3.68
W stock, seconds	2.80	0.82	3.62
	Experiment D, 1927		
H stock, firsts†	0.00	18.70	18.70
H stock, seconds‡	0.00	41.40	41.40
McJ. stock, firsts	4.76	0.00	4.76
McJ. stock, seconds	3.55	3.91	7.46

*Net necrosis in excess of the certification tolerance of the state of origin.
†Net necrosis 7%.
‡Net necrosis 6%.

We conclude, therefore, that the percentage of mosaic and leaf-roll developing in the plants grown from certified seed of good quality is not affected by the size of the seed stock purchased.

THE POINT BINOMIAL FORMULA FOR EVALUATING AGRONOMIC EXPERIMENTS[1]

S. C. SALMON[2]

The point binomial formula for calculating a standard deviation has not been generally applied to agronomic experiments. There seems to be no good reason why it should not be used in certain cases, so it seems worth while to call attention to some of these applications.

If two varieties which tend to yield alike are compared, it may be expected on the average of a large number of trials that each will exceed the other half the time. If one be considered a success and the other a failure, p and q will each be equal to 0.5. The standard deviation may then be secured by the well known formula, $\sigma = \sqrt{p.q.n.}$, where p and q are the expected probabilities expressed as decimal fractions and n is the total number of comparisons. The probable error will then be, $\epsilon = 0.6745\sqrt{0.5 \times 0.5 \times n}$. Substituting 2/3 for 0.6745 and removing the constant 0.5 from the radicle for convenience[4] the equation becomes

$$\epsilon = \tfrac{2}{3} \cdot \tfrac{1}{2}\sqrt{n} = \tfrac{1}{3}\sqrt{n} \qquad (1)$$

That is to say, the probable error may be secured by the simple expedient of extracting the square root of the number of cases or measures and dividing by 3.

To take a simple illustration, Kanred and Turkey winter wheats have been grown in 648 cooperative tests with farmers in different parts of Kansas during the past 15 years.[3] On the basis of chance alone, Kanred should have exceeded Turkey in yield 324 times. The actual number is 429. Turkey exceeded Kanred 216 times and there were 6 ties. Dividing the ties equally, as they would have been had the determinations of yield been sufficiently accurate, we may credit to Kanred 432 successes and 219 failures. The deviation from the expected number is, therefore, 108, i.e., 432–324.

The probable error is $\tfrac{1}{3}\sqrt{648} = 8.5$ and $\frac{D}{\epsilon} = \frac{108}{8.5} = 12.7$.

In other words, the ratio of the deviation to its probable error is 12.7. In these 648 trials, Kanred has averaged 22.72 bushels and Turkey 21.20 bushels. The difference is, therefore, 1.52 bushels.

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[1] Contribution No. 184, from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication June 27, 1929.

[2] Professor of Farm Crops.

[3] The writer is indebted to Professor H. H. Laude for the data used in this and the following illustration.

The probable error of this difference calculated in the usual way is 0.12 bushel and, hence,

$$\frac{D}{\epsilon}=\frac{1.52}{0.12}=12.7,$$

a value identical with that secured by the point binomial method. The significant difference lies in the fact that by the usual method an hour or two is required to make the necessary calculations with numerous opportunities for error, while only a very few minutes are necessary by the point binomial method and there are few opportunities for error.

Another example is afforded by a comparison of Kanota and Red Texas oats also grown in cooperative tests with farmers. In this case 208 comparisons have been made. In these, Kanota exceeded Red Texas in yield 182 times, whereas Red Texas outyielded Kanota only 26 times. The deviation is 78, i.e., $\frac{208}{2}-26$, and the probable error is 4.8, i.e., $\frac{1}{3}\sqrt{208}$.

$$\text{Therefore, } \frac{D}{\epsilon}=\frac{78}{4.8}=16.3.$$

The average yields are 39.28 and 29.37 bushels, a difference of 9.11 bushels and the probable error of this difference calculated in the usual way is 0.48. Hence,

$$\frac{D}{\epsilon}=\frac{9.11}{0.48}=19.0$$

which, although not so close as in the Kanred-Turkey comparison, nevertheless agrees very well with the point binominal method.

Additional comparisons for a considerable number of cases of injury by artificial freezing secured by the method described by Hill and Salmon (1)[4] have also been made. These, together with those just mentioned, are presented in Table 1. In the artificial freezing tests, there were many ties as a result of complete killing or of no injury whatever. Such cases were omitted from the data since the assumtion as to equal distribution between successes and failures will not hold as in the yield trials.

The first column of the table indicates the varieties that are compared, that one with the higher yield or the less injury, as the case may be, being mentioned first. Column 2 gives the number of comparisons (N) in each trial; and columns 3, 4, and 5, the probable error, the difference, and the ratio of the difference to the probable error, each calculated in the usual way. Columns 7 and 8

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[4] Reference by number is to "Literature Cited," p. 81.

TABLE 1.—*Probable errors and ratios of differences to probable errors calculated in the usual way and by the point binomial method.*

	N	P. E.*	D	D/P. E.	p	q	E	D′	D′/E
Yields:									
Kanred-Turkey	648	0.12	1.52	12.7	0.66	0.34	8.5	108	12.7
Kanota-Red Texas	208	0.48	9.11	19.0	0.87	0.13	4.8	78	16.3
Freezing Injury:									
Harvest Queen-Fulcaster	35	3.2	22.3	7.0	0.86	0.14	1.9	12.5	6.6
Harvest Queen-Fulcaster	61	1.8	11.3	6.3	0.82	0.18	2.6	19.5	7.5
Kanred-Tenmarq	17	2.6	12.3	4.7	0.88	0.12	1.4	6.5	4.6
Kanred-Tenmarq	46	2.5	30.5	12.2	0.89	0.11	2.3	18.0	7.8
Kanred-Tenmarq	45	3.0	34.2	11.4	0.93	0.07	2.2	19.5	8.9
Kanred-Tenmarq	68	1.8	20.7	11.5	0.93	0.07	2.8	29.0	10.4
Kanred-Nebraska 28	134	1.7	26.1	15.4	0.86	0.14	3.9	48.0	12.3
Kanred-Nebraska 28	47	3.0	42.9	14.3	0.96	0.04	2.3	20.5	8.9
Kanred-Nebraska 28	113	2.2	40.1	18.2	0.92	0.08	3.5	47.5	13.6
Kanred-Nebraska 28	67	2.2	34.0	15.5	0.98	0.02	2.7	32.0	11.8
Kanred-Nebraska 28	69	2.2	34.9	15.9	0.99	0.01	2.8	33.5	12.0
Kanred-Blackhull	19	1.6	11.3	7.1	0.89	0.11	1.4	7.5	5.4
Kanred-Blackhull	11	3.8	28.2	7.4	0.95	0.05	1.1	5.0	4.5
Kanred-Blackhull	20	5.4	22.0	4.1	0.78	0.22	1.5	5.5	3.7
Kanred-Blackhull	180	0.7	9.7	13.9	0.88	0.12	4.5	67.5	15.0
Kanred-Blackhull	46	2.5	27.7	11.1	0.85	0.15	2.3	16.0	7.0
Kanred-Blackhull	20	1.1	11.0	10.0	0.87	0.13	1.5	12.5	8.3
Kanred-Blackhull	22	4.3	29.0	6.7	0.87	0.13	1.6	7.0	4.4
Kanred-Blackhull	71	2.5	20.6	8.2	0.82	0.18	2.8	23.0	8.2
Winter barley—winter oats	43	1.4	10.4	7.5	0.79	0.21	2.2	12.5	5.7

*P. E. = Probable error calculated in the usual way and expressed as bushels or percentage of injury, as the case may be.

E = Probable error calculated by the formula: $E = \frac{1}{3}\sqrt{n}$.

D = Mean difference in bushels or percentage of injury.

D′ = Deviation from a 1:1 ratio.

give the observed values of p and q, column 8 the probable error (E) of the number of successes calculated by the point binomial formula, column 9 the deviation from the expected number of successes, and column 10 the ratio of this deviation to its probable error.

The agreement between the values in columns 5 and 10 it will be noted is in most cases very good. In some cases it is not as good perhaps as might be expected, but consideration of the probable error of these values (2, p. 228, and 4, p. 443) will show that in no case is the difference greater than may be explained by chance fluctuations.

It may be assumed that cases will be found in which p and q do not equal 0.5 or in which there is no *a priori* reason to expect any particular value of p and q. In such cases, the appropriate theoretical values or the observed values of p and q should be substituted for those assumed in formula 1, except that it should be noted that when p and q depart widely from 0.5 the curve is no longer normal and unreliable results may follow.

Use may sometimes be made of the fact (5, p. 265) that when the proportion of failures (or successes) is very small, the standard deviation of the number of failures is equal to the square root of the mean number of failures. That is

$$\sigma = \sqrt{nq}$$

and

$$\epsilon = \tfrac{2}{3}\sqrt{nq} \qquad (2)$$

As a matter of fact, it can be shown that formula 2 gives a result identical with formula 1, when $q = 0.25$. Thus, setting the two equal to each other and solving for q, gives

$$\begin{aligned} \tfrac{2}{3}\sqrt{nq} &= \tfrac{1}{3}\sqrt{n} \\ \tfrac{2}{3}\sqrt{q} &= \tfrac{1}{3} \\ \sqrt{q} &= 0.5 \\ q &= 0.25 \end{aligned}$$

Thus, where the proportion of failures is 25% or less or where observed values must be used and q is 0.25 or less, formula 2 will be found convenient.

Perhaps it should be pointed out that the agreement is not always good when n is small. This is illustrated in Table 2 which gives the result of applying various fertilizers to oats in Delaware as reported by Schuster (3). The yield figures are the yearly and average gains for treated as compared with untreated plats. The last column but one gives the odds as calculated by the so-called Student method and the last column the odds as calculated by formula 1. The differences, although no greater than may be explained by chance errors, are nevertheless greater than might be expected.

TABLE 2.—*Gains in yield of oats at the Delaware Experiment Station as a result of applying fertilizers.*

Plat No.	Fertilizer treatment	Gain in bushels per acre over untreated plat							Odds	
		1908	1909	1910	1911	1915	1917	Avg.	By Student method	By point binomial
5	NP	—0.7	8.1	20.6	2.4	6.5	4.5	6.9	26	9
7	PK	3.9	6.4	10.5	6.1	7.7	1.9	6.1	908	78
9	NPK	3.9	7.3	19.5	10.4	6.6	10.3	9.7	253	78
10	2 (NPK)	4.9	7.1	23.6	8.5	7.6	14.1	11.0	164	78
12	NPK & GM	0.6	14.9	23.4	—5.0	5.6	5.4	7.5	14	9
14	M	—0.1	0.2	26.9	15.7	5.8	7.2	9.3	7	9
15	2M	6.3	11.9	17.7	17.7	7.5	1.5	10.5	199	78

The significant fact would seem to be that neither method is reliable, nor can any method be reliable when n is no greater than 6 and where the data are so variable. The disagreement is made greater by the fact that the odds by the point binomial formula reach a maximum value at about 78 when n is equal to 6. Then, using formula 1, the probable error is 0.83. The maximum deviation that can be secured is 3, and hence $D/E = \frac{3}{0.83} = 3.7$, corresponding to odds of about 78 to 1. Perhaps this is fortunate.

At least it may be said that for those who insist on applying statistical methods when n is small, formula 1 sets up a barrier against a too optimistic interpretation of results and tends, in a measure, to guard against a false sense of security merely because the odds are high.

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THE INFLUENCE OF VARIOUS TOP-CUTTING TREATMENTS ON ROOTSTOCKS OF JOHNSON GRASS (*SORGHUM HALEPENSE*)[1]

D. G. Sturkie[2]

INTRODUCTION

Johnson grass is one of the major crops in many sections of the South. It is also a serious pest in many fields where cultivated crops are grown. A knowledge of the influence of the cutting stage on the rootstocks and the following crop should be valuable in planning a system of field management to produce the most economical hay yields and in exterminating it as a pest, since it is by means of these rootstocks that new plants develop the following year.

The main objectives of this study on the rootstocks of Johnson grass were (a) to ascertain when they were developed, and (b) to determine the effect of the stage of cutting on their development and the yield of tops.

REVIEW OF LITERATURE

Cates and Spillman (1)[3] classified the rootstocks of Johnson grass into three classes as follows: "1. Primary rootstocks, or those that are alive in the ground at the beginning of the growing season in the spring. 2. Secondary rootstocks, or those that arise from the primaries, grow to the surface, and produce crowns. 3. Tertiary rootstocks, or those that the plant sends out from the crown." They observed that the primary and secondary rootstocks decay each year, leaving only the tertiary ones (ones developed that year) to live over winter and produce new plants the following year. They observed that the farming system affected the rootstocks and concluded that frequent plowing or cutting reduced the tertiary rootstock growth and caused them to develop near the surface of the soil. In studying when the tertiary rootstocks were formed, they concluded that they were formed about flowering time and developed rapidly after that, but that even if plants were not permitted to develop flowers they would develop a small amount of tertiary rootstocks.

Other workers have studied the influence of cutting treatments on various grasses. Waters (2), working with timothy, concluded

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[2] Assistant Agronomist.

[3] Reference by number is to "Literature Cited," p. 93.

that early cutting reduced the stand, while late cutting maintained it. He obtained the largest yield of hay by cutting when seed were formed. Trowbridge (3), in studies on root storage in timothy, concluded that the bulbs increased in dry matter throughout the growing season but reached the maximum before the plant was ripe. Albert (4), in studies on redtop and bluegrass, concluded that frequent cutting reduced root and rhizome development by at least 50% and consequently reduced the stand and the yield the following year. The maximum yields of dry matter were obtained by cutting in the mature stage.

METHODS

Two types of experiments were conducted, *viz.*, in the greenhouse and in the field. The greenhouse experiments were run as a preliminary to field work. In each case plants were started from seed. The plants were harvested by hand and cut so as to leave a stubble 1 inch high. They were placed in an oven immediately after harvesting, dried, and weighed. In the rootstock studies the roots were carefully dug, the tertiary rootstocks removed, cleaned, placed in an oven immediately, dried, and weighed. The old rootstocks were discarded.

All pots and plats were fertilized at the rate of 2 tons of ground limestone, 1,000 pounds of superphosphate, 500 pounds of kainit, and 200 pounds of nitrate of soda per acre at planting. Nitrate of soda was added at the rate of 200 pounds per acre as often as plants showed signs of nitrogen hunger.

EXPERIMENT I, GREENHOUSE STUDIES ON TIME OF ROOTSTOCK FORMATION

In order to study the time of rootstock formation, cultures of Johnson grass were grown in the greenhouse and harvested at weekly intervals. Two-gallon pots were filled with fertile Norfolk sandy loam soil to which the fertilizer had been added. Seeds were planted and the plants thinned to five plants per pot. Two pots were harvested each time and the weights of rootstocks averaged. The top weights were also determined and the weights for the two pots averaged. The results of this experiment are shown in Table 1.

From Table 1 it is seen that no rootstocks appeared until the heads were showing. They developed as the seed did, making the most rapid growth as the seed matured. It appears that there is a transfer of food from the tops to the rootstocks as the plant reaches maturity, resulting in a decrease in weight of the tops and an increase in weight

TABLE 1.—*Time of formation of rootstocks by Johnson grass plants grown from seed in pots.*

Age harvested in weeks	Stage of growth	Dry weight in grams Tops	Dry weight in grams Rootstocks
1	2¾ inches high	0.3	0.0
2	4 inches high	0.8	0.0
3	10 inches high	2.1	0.0
4	16 inches high	6.8	0.0
5	31 inches high (booting)	11.5	0.0
6	Heading	23.3	1.0
7	Blooming	31.2	3.6
8	Seed in milk stage	38.8	6.2
9	Seed in dough stage	55.8	8.8
10	Some seed mature	50.7	11.1
11	Most of seed mature	41.6	14.3
12	Seed well matured	42.2	23.0

of rootstocks. Since no weights were taken for the seed, it cannot be said that they increased in weight, but it seems logical that they did. Johnson grass appears to use most of its energy toward reproduction. Unfortunately, the experiment was not run at different seasons of the year so it cannot be said that if seed germinated late in the season the plants would act in a similar manner. From observations in the field it was noticed that late in the season the plants develop some tertiary rootstocks, even though no heads appeared. It is possible that greenhouse conditions forced rapid top growth at the expense of rootstock development.

EXPERIMENT II, GREENHOUSE STUDIES ON EFFECT OF TIME OF CUTTING ON ROOTSTOCK DEVELOPMENT

In order to study what effect the stage of cutting had on the development of tertiary rootstocks and on those that were already developed a series of cultures were grown in the greenhouse and harvested at different intervals. Four-gallon pots were filled with Norfolk sandy loam soil of good fertility to which the fertilizer had been added. The seed were planted and after germination the plants were thinned to five plants per pot. Any plants which came up later from hard seed were removed as they appeared. The pots were planted in duplicates. The treatments were in series as follows: Series 1 was cut continuously throughout the growing season. Series 2 was permitted to mature a crop of seed before cutting treatments were started. This was done in order to permit a good system of rootstocks to develop before starting cutting treatments. The results of this experiment are shown in Table 2.

The data in Table 2, Series 1, show that the amount of rootstock development is reduced as the plants are harvested earlier, those cut when the plants were 2 feet high having only 5 grams of rootstocks, while those cut at maturity have nearly 60 grams. Any cutting treatment, regardless of how late, reduced the amount of rootstocks formed as evidenced by those cut at maturity weighing nearly 60 grams, while those not cut weighed 108 grams. There was less rootstock development when the plants were cut in the late milk stage than when cut in the blooming stage. This is probably an error.

TABLE 2.—*The effect of time of cutting on the rootstock development of Johnson grass in the greenhouse.*

Stage cut	Series 1 Number of cuttings	Series 1 Dry weight in grams Tops	Series 1 Dry weight in grams Rootstocks	Series 2 Number of cuttings	Series 2 Dry weight in grams Tops	Series 2 Dry weight in grams Rootstocks
1 foot high	4*	6.8	0.0			
2 feet high	6	27.2	5.0	5	73.0†	7.7
Booting	5	53.8	11.2	4	80.5†	22.5
Blooming	3	95.5	48.4	3	114.0†	40.6
Late milk	3	103.5	37.1			
Mature	2	111.1	59.7			
At end of growing season	1	——	108.0			

*The plants died by the middle of the summer.

†Weights include the amount of tops harvested when the plants reached maturity.

In Series 2 the plants were permitted to mature a crop of seed before cutting treatments were started, thus allowing the rootstocks to be well developed as shown in Experiment I. While the data in Table 2 do not give the weight of rootstocks when cutting was started in Series 2, the data in Table 1 indicate that the rootstocks weighed 23.0 grams when the plants reached maturity the first time. The results in this series show, therefore, that it is possible to exhaust the rootstocks by cutting frequently. Those cut in the 2-foot stage had only 7.7 grams of tertiary rootstocks by the end of the season. Apparently this cutting treatment had reduced the weight of rootstocks from 23.0 to 7.7 grams. This is very little more than was produced when the plants were cut continuously. When cut in the booting stage, there was no apparent increase or decrease in rootstock development. Cutting at blooming apparently permitted rootstock development since the weight increased from 23 to 40 grams.

The amount of tops produced in each series was reduced as the cutting was made more frequent. Those cut continuously at 2 feet produced 27.3 grams, while those cut when the plants were mature produced 111.1 grams. Thus, both rootstock and top development were reduced by frequent cutting treatments.

EXPERIMENT III, FIELD STUDIES ON EFFECT OF TIME OF CUTTING ON ROOTSTOCK DEVELOPMENT

In order to study the effect of the stage of cutting on the development of rootstocks of Johnson grass, a series of tests in the field were planned. Plats 4 x 5 feet in size were used. They were arranged in six tiers with an alley 5 feet wide on one side of a tier and an alley 2 feet wide on the other. It is noted that alleys of different widths were used. The 5-foot alley was used so that any plat in any tier could be dug without disturbing any other plat. An alley 2 feet wide was left between plats in a tier. All alleys were kept bare to prevent rootstocks from outside the plats spreading into them.

The soil used was a Norfolk sandy loam of average fertility. It was well prepared, the plats were laid off, fertilized, and on April 28, 1927, seed was planted at the rate of 50 pounds per acre. Each plat treatment was replicated five times, making six plats for each treatment. These were staggered over the area so that any treatment in any series could be compared with any other. In addition, three plats were planted which were to be dug when the plants reached maturity. The height of the plants was determined by measuring the average height as they stood normally and not by measuring to the tip of the longest leaf blade. In those cases where the stage was determined by the vegetative growth, cuttings were made when the majority of the plants reached that stage. Table 3 shows the stages of cutting that were used.

In Series 1 the cutting treatments were started as soon as the plants reached the indicated stage and were cut thereafter as often as they reached this stage. In the fall of 1927, three plats in each treatment were dug to determine the amount of rootstocks that had developed. The three plats left in each treatment were cut in the same stage during the summer of 1928 and dug after frost in the fall of 1928.

In Series 2 the plants were permitted to mature a crop of seed in the summer of 1927 before the cutting treatments were started. This was done in order to have a good system of rootstocks developed so that the effect of cutting treatments on them might be studied. On August 2 the seed was mature and the tops were harvested. The rootstocks on three plats were dug in order to determine the amount of rootstocks that were present at this time. These were the three additional plats previously referred to and did not enter into the cutting treatments. During the rest of the growing season the plants were harvested as often as they reached the desired stage of development. At the end of the growing season three plats in each treatment were dug. The remaining three plats in each treatment were left and during the summer of 1928 the plants were harvested as often as they attained the proper stage of development. The plants were not permitted to develop a crop of mature seed this year before cutting treatments were started as had been done in 1927. After frost in the fall of 1928 the roots on these plants were dug.

In Series 3 the plants on all the plats were permitted to grow during the summer of 1927 without cutting. This was done in order to have a good rootstock system at the beginning of the season of 1928. During 1928 the influence of this large system of rootstocks under various top-cutting treatments on top growth and in turn on the development of new rootstocks was studied. Since Johnson grass develops a new system of rootstocks each year, by the end of 1928 those of 1927 would be decayed and would not be represented in the weight of rootstocks at the end of 1928. Before growth started in the spring the dead tops were removed from all the plats in this series. The plants were harvested as often as they reached the proper stage during the summer of 1928. In this series three plats which had been cut in the booting stage until the middle of the summer were permitted to grow uncut during the remainder of the summer in order to study the ability of the plant to develop rootstocks late in the season. The results of this experiment are shown in Table 3.

From the results in Series 1 it appears that any cutting treatment causes a reduction in the amount of rootstocks that are formed as shown by the fact that plants cut at maturity produced only 774 grams of rootstocks, while those not cut produced 1,180 grams. The more frequently the plants are cut the greater is the reduction in rootstock formation. The plants that were cut in the 1-foot stage developed only 130 grams of rootstocks. These results agree very closely with those of the experiment in the greenhouse. (See Table 2.) This reduction continued the second year as all the cutting treatments showed less rootstocks present at the end of the second year than at the end of the first. The reduction was much greater in case of the plants that were cut frequently. Those cut in the 1-foot stage produced 130 grams the first year and only 10 grams the second, while those cut when the seed were mature produced 774 grams the first year and 739 grams the second. It is noted that under field conditions it was not possible to prevent entirely rootstocks developing by cutting when the plants were 1-foot high as was the case in the greenhouse.

The yield of tops was also reduced by frequent cutting treatments. The largest yield of tops was produced by cutting either when the

TABLE 3.—*Effect of stage of cutting on top and rootstock development of Johnson grass in the field.*

Treatment No.	Stage cut	Series 1, cut continuously						Series 2, permitted to mature a crop of seed before starting cutting						Series 3, permitted to grow for one year before starting cutting, 1928		
		1927 results			1928 results			1927 results			1928 results					
		No. cuttings	Dry weight in grams Tops	Dry weight in grams Rootstocks	No. cuttings	Dry weight in grams Tops	Dry weight in grams Rootstocks	No. cuttings	Dry weight in grams Tops	Dry weight in grams Rootstocks	No. cuttings	Dry weight in grams Tops	Dry weight in grams Rootstocks	No. cuttings	Dry weight in grams Tops	Dry weight in grams Rootstocks
1	1 foot high	5	935	130	8	431	10	3	2,100	658	7	470	11	9	1,262	45
2	2 feet high	4	1,504	262	5	752	51	3	2,141	608	5	820	75	6	1,646	110
3	Booting	3	1 574	321	4	1,270	139	2	2,110	604	4	904	74	4	2,363	383
4	Blooming	3	2,018	408	3	1,808	184	2	2,087	772	3	1,511	191	3	2,577	479
5	Seed in late milk	2	2,217	589	3	2,460	495	2	2,287	811	3	2,396	345	3	3,404	799
6	Seed mature	2	2,326	774	2	1,909	739	–	——	——	–	——	——	2	2,650	802
7	At end of growing season	–	1,221	1,180	–	1,678	1,281	–	1,221	1,180	–	1,678	1,281	–	——	——
8	Dug when seed mature (August 2, 1927)	–	——	——	–	——	——	–	1,811	1,055	–	——	——	–	——	——
9	Booting until middle of season (July 5)	–	——	——	–	——	——	–	——	——	–	——	——	2	1,200	526

seed was in the late milk stage or when it was mature. The plants cut in the 1-foot stage produced 935 grams of tops the first year and 431 grams the second, while those cut when the seed were in the late milk stage produced 2,217 grams the first year and 2,460 grams the second. It is seen that the reduction is much greater the second year than the first in the case of plants cut frequently. The weight of rootstocks at the end of the second year indicated that the reduction in top growth would continue the next year and eventually the plants would be thinned or entirely eradicated. The plants cut in the late milk stage or later yielded about as much the second year as the first, indicating that this is the best stage to cut for hay in order not to reduce future yields.

By cutting frequently it was possible to exhaust rootstocks which were already formed as shown in the results in Series 2. These plants had developed a good system of rootstocks (1,055 grams per plat) before cutting was started. The cutting treatments reduced these by fall to a very marked extent as shown by the plants cut at the booting stage having only 604 grams of rootstocks. Most of this reduction in weight was in the food reserves of the rootstocks as the yield of tops the following year was no larger than that in Series 1. Thus, any advantage of a well-developed system of rootstocks had been obliterated by fall. These results agree with those in the greenhouse as shown in Table 2.

The cutting treatments the second year hindered rootstock formation so that by the end of the season there were no more rootstocks present than in Series 1 which had been cut continuously. Cutting the plants in the early stages of growth reduced rootstock formation much more than cutting in the late stages. This is in agreement with the nature of the plant, as Johnson grass develops a new system of rootstocks each year from the new plants which are formed, the old rootstocks dying. Frequent cutting reduces the number and extent of new rootstocks that can be developed.

The yield of tops in Series 2 was nearly the same in all the cutting treatments the first year. This was due to the large weight obtained when the plants were first cut at maturity on all the plats and also to the fact that all rootstocks were well supplied with stored materials and stimulated rapid top growth during the brief remainder of the season. The second year there were large differences in the yields of tops in the various cutting treatments, the more frequently cut plats producing the lowest yields. These yields were approximately the same as those in Series 1, showing that any advantage of the well-developed system of rootstocks had been entirely obliterated by the end of the first year.

The results in Series 3 show the advantage to Johnson grass of having a good system of rootstocks at the beginning of the season. In this series the plants had been permitted to grow unharvested for one year and had 1,180 grams of rootstocks per plat by fall. The frequent cutting treatments reduced the formation of rootstocks during the summer of 1928 so that by the end of the season there were only 45 grams present in case of the 1-foot cutting stage and 110 grams in case of the 2-foot cutting stage. As was the case in Series 1 and 2, the more frequently the cutting treatments were made the greater was the reduction in the amount of rootstocks that were formed. The amount of rootstocks that were formed in this series during 1928 was greater than in Series 1 or 2, showing that a good rootstock system at the beginning of the season aids in the formation of new rootstocks.

This series also shows that Johnson grass can develop a good system of rootstocks if left uncut late in the season even if it has been cut frequently until that time. The plants which were not cut after July 5 developed 526 grams of rootstocks per plat and those which were cut developed only 383 grams.

The yields of tops in this series shows the advantage of having a large system of rootstocks to start the season. The top yields were much higher in all cutting treatments than in Series 1 or 2. The amount of top growth during a year is influenced very much by the amount of rootstocks that are formed during the previous year.

DISCUSSION

Experiments in the greenhouse showed that rootstock formation occurred simultaneously with seed formation when the plants were started from seed and were not cut. When the plants were cut and not permitted to head, some rootstocks developed before fall as shown in the greenhouse and in the field. When cutting was stopped in the middle of the season, the plants would develop a good rootstock system by fall. Experiments both in the greenhouse and in the field showed that any cutting treatment reduced the development of rootstocks. The more frequently the cutting was made, the greater was the reduction, but in the field it was not possible to prevent a small amount from forming during this test. When the plants were started from seed and cut continuously in the 1-foot stage for two years, there were 10 grams of rootstocks formed by the end of the season.

After rootstocks were well formed, it was possible to exhaust them by frequent cutting so that there was very much less present in the fall than there was in the middle of the summer. When plants were permitted to grow for one year before cutting was started and thus were allowed to form a large amount of tertiary rootstocks, it was possible to inhibit their reformation very much by frequent cutting. Thus, the plants acted very much like those which were started from seed and had no rootstocks when cutting was started. However, the amount of rootstocks present at the beginning of the season influences the top growth of the plants and this in turn influences the rootstock formation, so that the plants which had a good rootstock system to start the season formed more rootstocks than those which did not have one or that had only a small system.

By frequent cutting less total top growth was produced than under less frequent cutting. The largest yield of top growth was produced when the plants were cut in the late milk stage. The amount of top growth was influenced very much by the amount of rootstocks that were present. Plants with many tertiary rootstocks will produce much more top growth than those with few rootstocks, even though both are cut in the same stage. Permitting the plants to have a well-developed system of rootstocks at the beginning of the season increased the top yield 50% or more.

To control Johnson grass, when it is a weed, it is necessary to prevent it from developing a good system of rootstocks so that it will not be so vigorous the next year. Johnson grass can develop a good system of tertiary rootstocks after the middle of the season, and for this reason it often remains as a pest in cultivated fields in spite of attempts to eradicate it by cultivation early in the season. The main efforts at eradication should be spent from July until frost, as this is the critical time so far as rootstock formation and next year's growth are concerned

In hay production it is desirable to get as large continuous yields as possible. Cutting in the late milk stage produced the largest yields in all cases. Cutting as late as this stage did not reduce the yield the following year, while cutting prior to this time did. Cutting at this late stage does not produce the best quality of hay according to most recommendations. In order to produce the best quality of hay and at the same time not reduce the yield and thin out the stand, it is necessary to let the plants develop a system of rootstocks which is the food reserve for the next year's plants. This can be accomplished in two ways, namely, by stopping cutting in the middle of the summer or by cutting every other year. The plants which were not cut after the middle of the summer had 37% more rootstocks than those which were cut.

Unfortunately, there were no plats which were not cut during the latter part of the season on which yields were taken the following year. Those plats that were cut every other year yielded in 1928 over 50% more than those cut both years. The results from plats cut in the booting stage show that for 1927 and 1928 the total yield was 2,844 grams, while those cut only in 1928 yielded 2,363 grams. This gives a difference of 481 grams for which the labor of four cuttings was spent. Even on plats cut as late as the late milk stage, which stage did not reduce the yield and which gave the largest yield in all cases, the yield on those plats cut only in 1928 was so much larger than those cut in 1927 and 1928 as to suggest the desirability of cutting every other year. In 1928, the yield on the plats not cut in 1927 was 3,404 grams, while on those that were cut it was 2,460 grams. The total yield for 1927 and 1928 was 4,677 grams on those that were cut both years, and 3,404 grams for those cut only one year. This gives a difference of 1,273 grams for which the labor of three cuttings was spent.

Permitting the plant to develop a good system of rootstocks early in the season and afterwards cutting frequently will not be sufficient to maintain the yields. The yields in 1928 on plats which were treated in this manner in 1927 were no larger than on those which had been cut continuously. The late cutting treatment was just as injurious to the next year's yield as was the continuously cut one.

SUMMARY

The results of these experiments may be briefly summarized as follows:

1. Johnson grass develops rootstocks usually after the heads appear, but a few will form late in the season even if heads are not permitted to appear.

2. Any cutting treatment reduces the rootstock development, and the more frequently the cutting is made the greater is the reduction.

3. Cutting only during the latter half of the season did not reduce the weight of rootstocks as much as continuous cutting, but the top growth the next year was reduced as much, indicating that the cutting late in the season had reduced the food reserve much more than the weight of rootstocks indicated, and was just as effective as continuous cutting.

4. Cutting discontinued in the middle of the season permitted the plant to develop 40% more rootstocks than continued cutting.

5. Usually the largest yield of top growth was produced when the plants were cut when the seed was in the late milk stage.

6. The yield of top growth the second year was not reduced when the plants were cut when the seed was in the late milk stage, but when they were cut prior to this time it was.

7. Plants that started the season with a well-developed system of rootstocks yielded at least 50% more tops than those without such a system of rootstocks and also developed more new rootstocks during the season.

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2. Waters, H J. Part I, Studies of the timothy plant. Mo. Agr. Exp. Sta. Res. Bul. 19. 1915.
3. Trowbridge, P. F., Horgh, L. D., and Mouton, C. R. Part II, Studies of the timothy plant. Mo. Agr. Exp. Sta. Res. Bul. 20. 1915.
4. Albert, W. B. Studies on the growth of alfalfa and some perennial grasses. Jour. Amer. Soc. Agron., 19:624-654. 1927.

BOOK REVIEWS

BOTANY: PRINCIPLES AND PROBLEMS

By Edmund W. Sinnott. New York: McGraw-Hill Book Co., XXI+441 pages. illus. Ed. 2, revised. 1929. $3.

This second edition of Sinnott's Botany is rearranged and revised to include the latest developments in the science of botany. It is particularly suitable as an agricultural botany or reference text for agronomists, horticulturists, etc., or those whose interest in botany is chiefly agricultural.

It is written primarily as a college textbook in elementary botany, and the principles of general botany are clearly set forth and well illustrated. In addition to a well arranged presentation of the general principles of morphology, physiology and classification of plants, there is also a discussion of the principles of heredity and variation in plants. A distinctive feature of this book is the "Questions for Thought and Discussion" and the "Reference Problems," which are included at the end of each chapter. These questions are particularly stimulating and tend to give the student a broader conception of the field of botany and of the practical applications of its principles. (C. B. S.)

THE PLANT IN RELATION TO WATER

By N. A. Maximov. New York: The Macmillan Co. 451 pages, illus. 1929. $6.50.

Perhaps there is no phase of plant physiology of greater economic importance to agriculture than the use of water by plants. This subject has been covered very fully in the book cited. The purpose of the author was to present in a single volume an account of our present knowledge of the drought resistance of plants and of the important physical laws which govern the absorption and transpiration of water. The subject is treated under three heads, *viz.*, the absorption of water by the plant, the loss of water by the plant, and the water balance and drought resistance of plants.

The relation of the soil and of soil moisture to the plant is discussed and attention called in particular to the work of Briggs and McLane on the moisture equivalent of the soil and to the important experiments of Briggs and Shantz on the wilting coefficient. As early as 1859, however, Sachs recognized the difference in the water capacity of different soils and the importance of wilting as an indication of the point of so-called unavailable water in the soil.

In the English translation the author has omitted two chapters, which were included in the Russian text, dealing with the transfer of water through the plant body. He calls attention, instead, to the now generally accepted cohesion theory of Dickson to account for the rise of sap in tall trees. Dickson has shown that the cohesive force of water contained in small tubes is sufficient to account for the transpiration stream through tall trees with transpiration from the leaves as the lifting force.

In Part II, the author reviews the physical laws of evaporation, the relation of transpiration to evaporation, the daily march of transpiration, the stomatal apparatus of the plant, and the regulation of transpiration by the plant. The daily march of transpiration has been correlated with environmental factors in the experiments of Briggs and Shantz at Akron, Colo., and by the author at Tiflis. Both found that solar radiation, the intensity of sunlight, was the principal factor in determining the rate of transpiration. Atmospheric humidity was of second importance and air movement or wind of less significance.

Part III treats of a subject of more practical importance to agriculture. A land plant represents a sort of wick along which a continual stream of water is sent from the soil and escapes into the atmosphere. The total water content of a plant at any moment is small in comparison with the quantity that may pass through the plant during a day.

The author discusses leaf structure in relation to light and shade, atmospheric humidity, and soil moisture supply. High solar radiation, dry air, and low soil moisture supply, each tends to produce smaller and thicker leaves having more and larger veins than is the case in partial shade, humid air, and abundant soil moisture.

In the final chapter the subject of drought resistance in plants and its application to selection in plant breeding and to dry land agriculture is discussed. The essentials of a zerophytic structure are "a decrease in the size of all cells (including the stomata), a thickening of the cell walls, a strong development of palisade mesophyll, a denser network of veins, and an increase in the number of stomata per unit area. Physiologically, there is an increase in the intensity of transpiration and assimilation, in osmotic pressure, and in the capacity to endure wilting."

The author distinguishes between atmospheric drought with temporary wilting and soil drought producing permanent wilting. The most disasterous condition prevails when both occur as is frequently the case on the Great Plains of North America and on the Steppes of Siberia. It is suggested that the basis of drought resistance is to be found in the capacity of the plant (species or variety) to endure wilting. This adaptation probably is due to the specific properties of the protoplasm of different plants. (A. C. D.)

AGRONOMIC AFFAIRS

SUB-COMMISSION FOR PEAT SOILS

A session of the Sub-commission for peat soils will take place in Leningrad and in Moscow, U. S. S. R., from July 20 to August 2, 1930, in connection with the meetings of the VIth Commission and the Second International Congress of Soil Science. The session will be devoted to the reading and discussion of papers dealing with (1) stratigraphy, (2) profile analyses, and (3) cultural operations of peat lands. A comparative study of certain regional areas of "low moor" has been proposed with the view to adopting a uniform procedure and terminology in peat investigations.

Members who are interested and who may wish to present papers or attend the meetings are invited to send a brief summary of their contributions to Dr. A. A. Yarilov, President of the Organizing Committee, Iljinka, Karuninskaja 1, Gosplan, Moscow, U. S. S. R.

NEWS ITEMS

S. D. PRESTON, Assistant Extension Agronomist, Virginia Agricultural Extension Division, has resigned to do educational and demonstrational work for the American Cyanamid Company, effective January 1, 1930.

M. S. KIPPS, Assistant Agronomist, Virginia Agricultural Experiment Station, is spending the present academic year in graduate study toward the doctorate in agronomy at Michigan State College.

DR. H. H. LOVE of the Plant Breeding Department, Cornell University, on his recent return trip from China, spent two weeks at the Experiment Station of the Hawaiian Sugar Planters Association, studying in the field, the experiments now being conducted, the present methods now in use in the planting and harvesting of the plats, and the gathering of data. He was asked to make a study of these experiments, aid in the interpretation of experimental results, and to help plan new lay-outs for experiments with sugar cane. Special study was given to the number of repetitions, size and shape of plat, and number of samples necessary in order to be reasonably sure that the experimental data would be adequate for the purposes of the experiments. Lectures were also given on the aid of mathematics in the proper interpretation of experimental data.

MESSRS. KWAN, MA, and TANG, graduates from the College of Agriculture and Forestry of the University of Nanking, are taking graduate work in the Plant Breeding Department, Cornell University, in order to prepare themselves to aid in the Plant Improvement Project now being conducted cooperatively between Nanking University, Cornell University, and the International Education Board.

ERRATA

REGISTRATION OF CORN VARIETIES

The following portion of the report of the Sub-committee on Registration of Corn was omitted from the published report which appeared in the December,

1929, number of the JOURNAL, Pages 1196–1198. This portion should follow paragraph b, on page 1197, and should precede the heading "Application for the Registry of an Inbred Strain of Corn."

Data on the performance of a strain to be registered because of its inherent value must have been obtained using seed produced after three different generations of inbreeding of which the first shall constitute not less than the fourth generation of self pollination, or its equivalent.

No strain shall be registered on the basis of its value as a parent in a cross unless the other parental strains of that cross also are registered.

Data on the performance of crosses supporting applications for the registration of inbred strains must have been obtained using crossed seed produced anew following three different generations of inbreeding of which the first shall constitute not less than the fourth generation of self pollination of any of the parent strains.

APPLICATION FOR REGISTRATION

Each person submitting a selfed strain of corn for registration shall submit in triplicate, to the chairman of the Sub-committee on Registration of Corn, the information called for on the accompanying outlines of an "Application for Registration" and a "Description of Inbred Strain," and shall submit also 3 representative ears and 250 grams of seed of the inbred strain. Applications for registration of a strain because of its value in a cross must be accompanied also by 5 representative ears representing such cross.

KAWVALE WHEAT

Due to a typographical error, Kawvale wheat is misspelled on page 1199 of the December, 1929, number of the JOURNAL. This variety is correctly listed and described in the report of the Sub-committee on the Registration of Improved Wheat Varieties, IV, pages 1172–1174 of the December issue of the JOURNAL.

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INFLUENCE OF ALFALFA ON THE CHANGE OF VIRGIN SOILS IN THE COTTON DISTRICTS OF ARMENIA[1]

KH. P. MIRIMANOFF[2]

INTRODUCTION

The contribution reported here is the result of field investigations and analyses of soil samples collected in the Echmiadzin district of Armenia. This region is typical of the cotton districts of Armenia. Here cotton is the dominant crop, and hence, occupies an important place in the agriculture of the country.

As the area devoted to cotton increases, the problems of improving the physical, chemical, and biological properties of the soil assume great importance. After consideration of the environmental conditions of this district, attention was given to some areas, a part of which had never been cultivated (virgin soils), while other parts had been under cultivation for more than eight years.

The profiles from which soil samples were taken were selected from those which were the most representative of each soil type. Samples were taken from the virgin soil profiles as well as from the cultivated ones.

METHODS

The mechanical analyses of the soils were made by the new English method (6).[3] Mechanical fractions were classified according to that of the laboratory of soils of the Agricultural Academy of Moscow. The organic matter (humus) and CO_2 were determined by the Knop method and nitrogen by the Kjeldahl method. The water extracts were prepared from the soils by passing the soil through a I-mm sieve and shaking for 5 minutes, the ratio of soil to water being as 1:5. In these extracts, all elements, except sulfuric acid, were determined volumetrically.

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[1] Contribution from the Central United Laboratory of Armenia. Received for publication June 24, 1929.

[2] Lecturer at State University, Erivan, Armenia, U. S. S. R.

[3] Reference by number is to "Literature Cited," p. 107.

The H-ion concentration of the air-dried soils was established colorimetrically. The methods proposed by Gedroiz for the estimation of the replaceable bases in the soils, both with the solution of NH_4Cl and N / 0.05 HCl, cannot be applied in the presence of any considerable amount of CO_2, hence we used the more suitable method of Hissink (2).

Exchangeable calcium and magnesiun were determined volumetrically by titration. Exchangeable sodium was determined by the Barber and Kolthoff (3) method, but exchangeable potassium was defined as the difference between the sum KCl+NaCl and the exchangeable sodium.

The methods of Dojarenko (4) were used to determine some physical properties of these soils. The analytical figures reported below are averages of duplicate determinations, and all the calculations are made on a dry-matter basis.

RELIEF AND PARENT MATERIAL

The district under study, with the city of Echmiadzin in centre, is situated on the left bank of the Arax River, between two gigantic volcanic ridges—Ararat and Alagez—and covers the area of the northwestern part of the lowlands of the plateau of Armenia.

The surface of the Echmiadzin district represents a wide plain with a gradual decline to the south and southeast toward the river. The plain is surrounded with mountains and has an elevation of over 814 meters above sea level. It is composed of volcanic materials as well as pre-volcanic matter. The latter covers the low layers of the earth strata and consists of limestone, slates, and chalk-clays which come from the Tertiary period of the geological history of the land.

The horizontal layers of the shingles and various fragments of volcanic products, belonging to the Alagez's system, are laid on the above-mentioned materials of the Tertiary period. There are more recent lava flows of basalt and andesite which were brought down to the plain from the Alagez through the ancient alluvial and deluvial streams.

Abich (1) calls the above-mentioned deposits that cover the plain "Diluviale Ablagerungen auf den Thalebenen." The soils of the Echmiadzin district have developed on the products of the weathering of this volcanic material.

HYDROGRAPHY

The district is lacking in natural rainfall, and artificial irrigation is highly developed. The water system is dependent on the large amounts of rainfall that visit the Alagez Plateau each year. A part of this flows down to the Echmiadzin district along the surface of the mountain sides, while the remainder penetrates the cracks of the cooled volcanic lava to the clay foundation of the Tertiary period. Having reached the clay foundation, the water flows under ground through the shingles to the Arax River. This underground water springs out of the earth in numerous spots in forms of abundant streams and rivulets

Near the city of Echmiadzin the depth of the underground water is 3.8 meters, but the possibility of a capillary rise is excluded, due to the presence of natural drainage systems (shingles of considerable thickness) in the subsoil.

That this underground water is satisfactory will be seen from the following analysis made at the Echmiadzin Agricultural Experiment Station: HCO_3, 0.0236%; Cl, 0.0044%; SO_3 0.0236%; and color entirely transparent.

CLIMATIC CONDITIONS

In order to have a correct understanding of the climatic conditions of the district, the weather records of the Echmiadzin Meteorological Station for a period of 10 years are given in Table 1.

This station is situated at an elevation of 815 meters above sea level at 40° 10′ latitude and 44° 17′ longitude.

TABLE 1.—*Monthly precipitation and temperatures at Echmiadzin for a 10-year period.*

Month	Mean monthly precipitation in mm	Average monthly temperature in °C		
		Absolute maximum	Absolute minimum	Mean
January	13.4	8.0	—25.0	—3.6
February	13.2	6.2	—29.5	—1.2
March	20.8	19.0	—17.4	5.9
April	48.0	33.0	—4.4	10.6
May	49.4	33.5	6.7	18.5
June	19.4	35.0	8.5	22.7
July	15.9	36.2	12.8	25.7
August	11.9	38.4	13.4	26.4
September	5.8	34.2	6.4	21.6
October	15.0	26.5	0.2	14.3
November	17.0	20.5	—10.3	6.7
December	29.3	10.5	—18.6	1.3
Total	259.1	—	—	+12.45

As seen from the table, the highest monthly rainfall occurs in April and May and the lowest in August and September, with only slightly more in January and February. During the last two months the precipitation is mostly snow. From the figures for maximum, minimum, and mean monthly temperatures, it will be seen that the mean temperature is above freezing from March till December, inclusive.

Thus, the growing season is seven months, with a mean temperature of 20°C. This figure rises sharply, if the influence of the 815 meters height above sea level is excluded. In that case it shows the highest isothermal line in comparison with the other spots in Trans-Caucasia having the same latitude. It has been explained that the Echmiadzin and Erivan plains are surrounded by high mountains which exclude any influence of the Black and Caspian Seas. The very low temperature in winter is also due to the influence of the mountains.

In Table 2 is given the soil temperature for different depths.

TABLE 2.—*Soil temperatures.*

Month	Temperatures in °C at		
	5 cm	10 cm	20 cm
January	— 1.5	— 1.0	0.0
February	— 0.7	— 0.4	0.0
July	30.5	29.5	28.8
August	32.6	31.2	30.6

As can be seen from these figures, the soil is frozen to a depth of 20 cm from January to February.

Data on the average number of hours of sunshine during the year at Echmiadzin are presented in Table 3.

TABLE 3.—*Hours of sunshine for an average of six years.*

Month	Hours of sunshine	Month	Hours of sunshine
December	76.3	June	304.7
January	132.0	July	348.2
February	108.8	August	340.5
Total	317.1	Total	993.4
March	190.7	September	238.4
April	165.4	October	234.8
May	262.3	November	154.7
Total	618.4	Total	627.9

Finally, the winds that blow constantly from the northern highlands add to the aridity of the district.

NATURAL VEGETATION

The dry climate of the Echmiadzin district, with insufficient natural precipitation and with high summer temperatures and much evaporation, has an influence on the character of the natural vegetation. No culture is possible here without artificial irrigation.

The spring and autumn rains make possible an ephemeral growth of vegetation that soon perishes after the upper layers of the earth are dried out. However, there is an insignificant group of plants with a growing season which begins early in the spring and lasts until late in the autumn, made possible by root systems which enable the plants to obtain the necessary moisture from deep down. This group does not depend on the surface water. *Alhagi camelorum* Fisch. occupies the first place in this group, together with some species of *Artemisia maritima* L. and *Glycyrrhiza glabra* L. During the summer, in spite of the excessive dryness, these plants look very green and fresh.

Peganum harmala L. is also frequently found in the Echmiadzin district, sometimes in great quantity. According to Warming (5), *P. harmala* is a typical plant of the Egyptian desert.

Besides, upon the uncultivated areas, the following plants grow in abundance· *Salsola kali* L., *Xanthum spinosa*, and *Ceratocarpus arenarius*, while *Cynodon dactilus* is found very rarely.

EXPERIMENTAL

Under the influence of the climatic conditions prevailing in this region, the small amount of organic matter of the natural vegetation that is left after the plants die is soon decomposed and forms the so-called light brown soils.

For the purpose of investigating the influence of prolonged culture of alfalfa on this natural (virgin) soil, we shall consider the physical and chemical properties of the soil samples obtained from the different profiles that are representative of both virgin (uncultivated) and cultivated areas (with alfalfa).

PHYSICAL PROPERTIES

Table 4 shows the physical properties of the virgin soils taken from the profiles of uncultivated areas.

TABLE 4.—*Physical properties of virgin soils in Echmiadzin district.*

Depth in cm	True specific gravity	Porosity Capillary %	Porosity Non-capillary %	Porosity Total %	Water capacity %
0–9	2.28	44.46	3.54	48.00	45.07
9–42	2.30	37.69	9.08	46.77	40.10
42–70	2.34	45.45	0.67	46.12	45.63
70–90	2.34	40.81	2.13	42.92	40.92

The specific gravity is somewhat less for the surface layer than for the deeper ones, which is due to the fact that the upper layers contain comparatively more organic matter.

Total porosity, which is almost all capillary, is greater in the first layer and decreases downward. Non-capillary pore space is almost imperceptible. The water capacity varies from the surface layers downward.

Table 5 shows the physical properties for the soils under prolonged cultivation to alfalfa.

TABLE 5.—*The physical properties of soils after prolonged cultivation to alfalfa.*

Depth in cm	True specific gravity	Porosity Capillary %	Non-capillary %	Total %	Water capacity %
0–13	2.19	41.02	21.41	62.43	49.72
13–32	2.23	42.13	23.12	65.25	49.46
32–45	2.24	41.14	11.26	52.40	46.21
45–90	2.34	41.33	6.04	47.37	41.99

As can be seen from these figures, the specific gravity for the soils after prolonged cultivation to alfalfa is less than that for the virgin soils, especially in the first layer, due to the great amount of organic matter (humus).

For the same reason the cultivated soil contains a very high percentage of total porosity which increases downward to the second layer and then begins to decrease. In the upper layers the ratio of non-capillary porosity to capillary is near a 1:2 ratio. The non-capillary porosity is greatly increased in comparison with the virgin soils. Water capacity is higher in the first layer, where most of the organic matter is present, and gradually decreases in the lower layers.

MECHANICAL ANALYSES

The results of the mechanical analysis of the virgin soil are recorded in Table 6.

TABLE 6.—*The mechanical analyses of the virgin soils.*

Depth in cm	Gravel >2 mm	Medium sand 2–1 mm	Fine sand 1–0.25 mm	Very fine sand 0.25–0.05 mm	Silt 0.05–0.01 mm	Fine silt 0.01–0.005 mm	Very fine silt 0.005–0.001 mm	Clay <0.001 mm
0–9	4.31	6.12	12.78	20.31	10.52	30.24	11.80	3.92
9–42	5.97	5.15	9.32	18.55	10.12	34.04	12.45	4.40
42–70	6.02	4.18	8.40	20.12	13.11	32.00	12.05	4.12
70–90	10.20	7.00	12.14	22.00	10.12	25.37	10.03	3.14

These results show that the amount of gravel, medium sand, and fine sand fractions ()2–0.25 mm) is low, and with variations, increases towards the subsoil. The very fine sand fraction also increases in the same way. The total quantity of silt, fine silt, and very fine silt (0.05–0.001 mm) are the dominant fractions and decrease downwards. The clay fraction (⟨0.001 mm) shows a gradual decrease with depth from the second layer.

The total fraction between 0.01 and 0.001 mm shows a higher percentage of these in the second layer of soil, due doubtless to the fact that rainfall tends to carry the fine particles of soil into the second layer.

Table 7 gives the results of the mechanical analysis of soils after prolonged cropping to alfalfa.

TABLE 7.—*The mechanical analysis of soils after prolonged cropping to alfalfa.*

Depth in cm	Gravel >2 mm	Medium sand 2-1 mm	Fine sand 1–0.25 mm	Very fine sand 0.25–0.05 mm	Silt 0.05–0.01 mm	Fine silt 0.01–0.005 mm	Very fine silt 0.005–0.001 mm	Clay <0.001 mm
	%	%	%	%	%	%	%	%
0–13	1.92	5.12	7.28	14.35	11.36	36.47	16.78	6.72
13–32	3.94	7.54	11.36	19.57	10.00	32.02	10.74	4.82
32–45	3.32	2.75	9.63	16.52	12.36	37.23	13.99	4.20
45–90	12.57	6.17	15.55	19.02	7.20	24.31	12.42	2.76

It can be seen from these figures that in comparison with the figures given in Table 6, the fractions from ⟩ 2 mm to 0.05 mm decrease in the first layer in the cultivated soil, while the fractions from 0.05 mm to 0.001 mm increase. Thus, the process of the formation of fine soil particles is speeded up under prolonged cultivation to alfalfa.

AMOUNT OF ORGANIC MATTER AND NITROGEN CONTENT

Data on the humus content, total nitrogen, and CO_2 content of the virgin soil are presented in Table 8.

TABLE 8.—*Amount of humus, nitrogen content, and CO_2 in virgin soils.*

Depth in cm	Hygroscopic moisture	Total humus	Water-soluble humus	Ratio water-soluble humus to total humus	N	CO_2
	%	%	%	%	%	%
0–9	3.49	0.81	0.0203	1:40	0.049	1.078
9–42	3.54	1.11	0.0194	1:60	0.143	0.875
42–70	3.52	0.75	0.0178	1:42	0.103	0.965
70–90	3.45	0.54	0.0135	1:40	0.102	1.342

It will be seen from Table 8 that the amount of humus in the first layer is less than 1%, while in the second layer it is slightly more than 1%, decreasing toward the lower layers. In comparison with the small amount of organic matter, the nitrogen content is considerable, reaching 0.143% in the second layer and decreasing gradually downwards. The surface layers contain less nitrogen than the lower ones. The amount of CO_2 is quite high, exceeding 1% in the top soil. This is doubtless due to the capillarity of the soil. In the second layer the CO_2 is lower and decreases downwards.

Table 9 shows the results of analyses of the soils after prolonged cropping to alfalfa.

TABLE 9.—*Amount of humus, nitrogen content, and CO_2 in soils cropped to alfalfa.*

Depth in cm	Hygroscopic moisture	Total humus	Water-soluble humus	Ratio water-soluble humus to total humus	N	CO_2
	%	%	%	%	%	%
0–13	4.19	2.92	0.0162	1:180	0.188	0.600
13–32	4.00	1.56	0.0104	1:150	0.084	0.098
32–45	4.27	0.77	0.0143	1:54	0.081	0.074
45–90	4.18	0.51	0.0108	1:47	0.056	0.088

A comparison of the results for these soils with those obtained for the uncultivated soils leads to the conclusion that prolonged cultivation to alfalfa rather increases the amount of humus in the upper layers, which in the top soil reaches 2.92%. Hygroscopic water also increases. The maximum nitrogen content is in the first layer, due to the great amount of organic matter. Total humus, as well as nitrogen, decreases gradually from the surface downward.

The percentage of CO_2 after eight years' cropping to alfalfa, on the contrary, is decreased greatly, except in the first soil layer where there is more CO_2 owing to an increasing capillarity in the soil. The decrease of CO_2 is doubtless due to the artificial irrigation practiced on the cultivated soil.

WATER EXTRACTS

Data on the analyses of the water extracts from the virgin soils is shown in Table 10.

TABLE 10.—*Percentage of elements in water extracts of virgin soils on basis of dry weight.*

Depth in cm	Hygroscopic moisture	Dry remnant	Solar remnant	Loss on ignition	Dissolved humus
	%	%	%	%	%
0–9	3.49	0.1367	0.1102	0.0265	0.0203
9–42	3.54	0.1400	0.1055	0.0345	0.0194
42–70	3.52	0.1650	0.1390	0.0260	0.0178
70–90	3.45	0.1570	0.1351	0.0219	0.0135

Depth in cm	Alkalinity								
	Na_2CO_3	HCO_3	$NaHCO_3$	$Ca(HCO_3)_2$	Cl	SO_3	CaO	MgO	pH
		%	%	%	%	%	%	%	
0–9	——	0.0720	0.0561	0.0159	0.0021	0.0052	0.0230	0.0032	7.81
9–42	——	0.0610	0.0501	0.0199	0.0091	0.0069	0.0210	0.0062	7.76
42–70	——	0.0610	0.0464	0.0146	0.0281	0.0172	0.0218	0.0102	7.76
70–90	——	0.0537	0.0330	0.0207	0.0337	0.0110	0.0254	0.0104	7.73

These soils, in the upper layers, contain a dry remnant of about 0.14%, which increases downwards. The percentages of solar remnants, however, are comparatively less. Loss on ignition is highest in the second layer, where it reaches 0.0345%, and from this depth slightly decreases downwards. The first layer contains the maximum amount of dissolved humus which also decreases gradually downwards.

The amount of alkalinity is considerable, reaching the highest figure in the top soils. It decreases towards the lower layers. The alkalinity depends mainly upon $NaHCO_3$. As a rule in these soils no normal carbonates are to be found.

The percentages of chlorine and sulfuric acid are low and increase in the lower layers, due to leaching. Total calcium and magnesium vary considerably, but increase toward the lower strata. All of the samples have pH values varying from 7.81 to 7.73.

TABLE 11.—*Percentage of elements in water extracts of soils long cropped to alfalfa on basis of dry weight.*

Depth in cm	Hygroscopic moisture %	Dry remnant %	Solar remnant %	Loss on ignition %	Dissolved humus %
0-13	4.19	0.0830	0.0630	0.0200	0.0162
13-32	4.00	0.0560	0.0452	0.0108	0.0104
32-45	4.27	0.0625	0.0447	0.0178	0.0143
45-90	4.18	0.0660	0.0538	0.0122	0.0108

Depth in cm	Alkalinity								
	Na_2CO_3	HCO_3 %	$NaHCO_3$ %	$Ca(HCO_3)_2$ %	Cl %	SO_3 %	CaO %	MgO %	pH
0-13	----	0.0390	0.0130	0.0260	0.0022	trace	0.0212	0.0010	7.68
13-32	----	0.0260	0.0123	0.0137	0.0028	----	0.0140	0.0021	7.62
32-45	----	0.0258	0.0195	0.0063	0.0036	trace	0.0073	0.0016	7.60
45-90	----	0.0264	0.0137	0.0127	0.0078	----	0.0151	0.0020	7.60

A comparison of the figures given in Table 11 with those obtained from water extracts of virgin soils leads to the following conclusions:

First, it is apparent that after prolonged cropping to alfalfa the total amount of dry remnant, as well as the solar remnant decreased almost half. The amount of dissolved humus and the loss on ignition were also reduced by half. Total alkalinity decreased by more than half and depends on both $NaHCO_3$ and $Ca(HCO_3)_2$. Normal carbonates were absent in all samples. The percentage of chlorine increased downward, while calcium oxide decreased. Only traces of sulfuric acid were present. Magnesium also visibly decreased as compared with the virgin soil.

The pH values of these soil samples varied from 7.68 to 7.60 as compared with a range of 7.81 to 7.73 in the cases of the virgin soils. The horizontal distribution of the elements is similar to that in virgin soils.

EXCHANGEABLE BASES

The results of studies of exchangeable bases in virgin soils and soils cropped to alfalfa are given in Table 12.

TABLE 12.—*Amount of replaceable bases in virgin soils.*

Depth in cm	Milligram equivalents in 100 grams dry soil					Percentage of replaceable cation to total of replaceable bases in 100 grams dry soil					
	Ca	Mg	Na	K	Total	Ca	Mg	Na	K	Ca+ Mg	Na+ K
0–9	15.00	8.22	3.81	1.42	28.45	52.72	28.89	13.40	4.99	81.61	18.39
9–42	17.05	6.60	6.84	2.37	32.86	51.89	20.09	20.81	7.21	71.98	28.02
42–70	12.77	6.00	3.47	1.20	23.44	54.48	25.60	14.80	5.12	80.08	19.92
70–90	9.20	6.41	3.40	1.09	20.10	45.77	31.89	16.91	5.43	77.66	22.34

From these data it can be seen that the virgin soils have 20 to 33 milligram equivalents of replaceable cations in 100 grams of soil. The sum of the equivalents from the first layer to the second increases, then decreases in the direction of the lower layers.

The replaceable bases in the soils after prolonged culture to alfalfa are shown in Table 13.

TABLE 13.—*Amount of replaceable bases in soils cropped to alfalfa.*

Depth in cm	Milligram equivalents in 100 grams dry soil					Percentage of replaceable cation to total of replaceable bases in 100 grams dry soil					
	Ca	Mg	Na	K	Total	Ca	Mg	Na	K	Ca+ Mg	Na+ K
0–13	24.30	7.40	2.13	3.87	37.70	64.45	19.63	5.65	10.27	84.08	15.92
13–32	16.75	6.58	3.40	3.64	30.37	55.13	21.67	11.20	12.00	76.80	23.20
32–45	14.10	8.63	3.05	2.69	28.47	49.53	30.31	10.71	9.45	79.84	20.16
45–90	10.35	9.04	3.41	1.42	24.22	42.73	37.33	14.08	5.86	80.06	19.94

By way of comparison of these figures with those obtained from virgin soil, it may be stated that the sum of replaceable cations rather increases in the cultivated soil, reaching 38 milligram equivalents in the first layer. The amount of replaceable Ca exceeds that in virgin soils and is largest in the surface layer, gradually decreasing downward. Magnesium decreases in the upper layers, but increases in the lower layers. The replaceable sodium decreases in the first and second layers, due to cultivation and to artificial irrigation. The leaching out of sodium leads to the saturation of the surface layers with calcium. The amount of exchangeable potassium in the soil is observably increased, but gradually decreases from the first layer toward the lower layers.

It is apparent that the relationships between different replaceable cations in soils after prolonged cultivation to alfalfa are changed remarkably in comparison with virgin soils.

SUMMARY

The prolonged cultivation of alfalfa had a favorable influence on the change of virgin, uncultivated soils in the Echmiadzin region which is typieal for the cotton districts of Armenia. This favorable influence is believed to be due to changes which may be summarized as follows:

1. In the virgin soils after prolonged cultivation to alfalfa the silt and clay fractions increased, especially in the upper layers.
2. The physical properties of soils after alfalfa cultivation were considerably improved, due to increasing non-capillary porosity and the raising of the water-capacity of the soil.
3. The amount of organic matter in the surface layers greatly increased.
4. The amount of hygroscopic moisture also increased.
5. The nitrogen content increased in the first layer, but decreased in lower layers.
6. A marked depression in CO_2 content was observed.
7. In water extracts from soils cropped to alfalfa the amounts of dissoluble salts decreased, due mainly to the decline of alkalinity.
8. The amount of exchangeable cations greatly increased in the upper layers, due to the increasing amounts of calcium and potassium. On the contrary, the amount of exchangeable sodium decreased remarkably.

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RESISTANCE OF WHEAT TO HIGH TEMPERATURES UNDER DIFFERENT METHODS OF HEATING[1]

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INTRODUCTION

The relationship between the water content of a seed and its state of life, more especially as expressed in its respiratory activity, has been known to botanists for many years. The water content and its bearing on the denaturing processes of the living protein is of more recent interest and its direct bearing on agricultural practices is even now overlooked. Too often recommendations for seed treatment are made without regard to this most important relation, and, in consequence, with more or less disastrous result to the farmer.

The object of the research reported in this paper is to show the significant relationship between the water content of seed wheat and its resistance to high temperatures. Also, the effect of heating under two sets of conditions will be considered.

REVIEW OF LITERATURE

An anonymous contributor (1)[3] reported that the thermal death point of *Trifolium pratense* was raised from 39° to 120°C as a result of reducing the water content of the seed

In 1899, Jodin (8) noted the relationship between water content of seed and resistance to high temperatures. He found that heating in an open vessel permitted the loss of water and increased the resistance of the seed to heat.

Dixon (4, 5), in 1901 and 1903, found that seed of various common crop plants dried over sulfuric acid was able to withstand a temperature of 90°C for several days. He reported that a longer period of heating was possible with well dried seeds. In one instance a temperature of 120°C for one hour did not destroy viability.

Shapovalov, reviewing Naumov (10) in 1916, reported that in studies of wheat scab and *Fusarium* spp., he was able to heat rye from 24 hours to 3 days at 66°C, and oats and barley at 60°C for the same period without affecting vitality. He failed to mention the method of heating or the moisture content of the seeds.

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[1] Contribution from the Department of Agronomy and the Division of Plant Physiology, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication July 13, 1929.

[2] Head of the Department of Botany, University of Illinois, and former graduate student in Agronomy and Plant Physiology; now Assistant Agronomist, Minnesota Agricultural Experiment Station, respectively.

[3] Reference by number is to "Literature Cited," p. 112.

Waggoner (12), from his work with radish seed, reported in 1917, that many workers had erred in their methods of heating seeds. He found that seeds heated in a moist atmosphere absorbed water, while those heated in a closed container gave up moisture as did those heated in a dry oven. He was able to overcome these difficulties by heating the seeds in tubes stoppered with finely drawn capillary tubes to permit adjustment of pressure. His research showed that the resistance of the radish seed to high temperature was inversely proportional to the initial water content of the seeds at the time of heating. Also, seeds showed great differences in resistance to temperature when heated under different methods.

Burgess (3) found the germination of wheat to be 68% when heated at a temperature of 90°C for one hour as compared with a check of 92%. Here, as usual, no mention was made of the water content of the seed or method of heating.

Atanasoff and Johnson (2), in 1920, as a result of work with dry heat in controlling diseases of cereals wrote, "Good dry seed of barley, wheat, oats, and rye is able to withstand surprisingly well the high temperatures used, up to 30 hours" The temperature referred to was 100°C. They report a germination record of 98% with Kanred wheat heated at a temperature of 100°C for 30 hours in a gas oven. No mention is made of the water content of the seed or of the details of methods employed in heating.

Kienholz (9), in 1924, reported the results of his work with corn germination as affected by temperature. He found that air-dry corn containing 10 to 11% water was destroyed in 25 minutes at 80°C and in 10 minutes at 90°C. Also, it was injured at 70°C in 80 minutes, at 80° in 10 minutes, and at 90° in 5 minutes. He noted that resistance to heat varied, both in the laboratory and outside, with changes in humidity.

Hoffman (6), in 1925, showed the effect of dry *vs.* moist heat on the germination of forest seeds. With dry heat, germination decreased greatly with an increase in temperature from 82.2° to 93.3°C. A similar decrease was effected with a rise from 60.0° to 71.1°C when moist heat was used. This experiment demonstrated the importance of water content in relation to injury from heating.

Staker (11), studying the effect of dry heat on alfalfa seed and its adulterants, heated the seeds in open flasks immersed in oil. He found that the germination of alfalfa decreased rapidly with temperatures above 90°C. No mention was made of the moisture content of the seeds or of the fact that the open-mouthed flasks gave opportunity for the water content of the seed to vary.

MATERIALS AND METHODS

Red Cross wheat grown at the Illinois Agricultural Experiment Station was used in the heating experiments. This variety was selected because it is a soft red winter wheat and the grain was quite free from the small breaks and cracks often found in the harder wheats. All seeds were carefully examined to eliminate any broken or injured kernels which were present.

Two-quart mason jars, 1 to 6, were furnished with different concentrations of sulfuric acid. The different concentrations were obtained by carefully mixing sulfuric acid with distilled water. The solutions were made up as follows:

Jar No.	Twadell reading	Sp. gravity
1	Water	1.000
2	14	1.070
3	28	1.140
4	42	1.210
5	56	1.280
6	70	1.350

About 1 pint of solution was placed in each jar. Small wire baskets, filled with wheat, were suspended from the jar lid in a manner which placed the bottom of the basket about 1½ inches from the liquid. These jars were sealed and placed in the basement of the Botany Annex during the summer of 1926, and in a 20°C thermostat during the fall and winter of 1926–27. Repeated weighings made in the spring of 1927 showed that the wheat had reached a constant weight and heating experiments were started.

Two methods of heating were employed. Seeds from the same lot were heated (a) in open containers in an electrically heated and controlled oven, and (b) in flasks stoppered with capillary tubes. The flask containing the seed was placed below the level of solutions with different constant boiling points. The heating solutions were made from mixtures of glycerine and methyl alcohol with water. A double condenser connected with the water faucet prevented a loss of vapor and a consequent change in the boiling point of the mixture.

The oven and the water bath were maintained for periods of 30 and 60 minutes, respectively, at the following constant temperatures: 70°, 80°, 90°, and 100°C.

RESULTS AND DISCUSSION

The data obtained in these experiments are presented in Tables 1 and 2.

TABLE 1.—*Specific gravity of solutions and water content of seed.*

Jar No.	Specific gravity	Water content %
1	1.000	27.5
2	1.070	21.1
3	1.140	15.4
4	1.210	13.3
5	1.280	11.7
6	1.350	9.9

TABLE 2.—*Percentage germination of wheat heated at different temperatures in water bath and in oven for periods of 30 and 60 minutes, respectively.*

	70°C				80°C				90°C				100°C			
Jar No.	Water bath		Dry oven		Water bath		Dry oven		Water bath		Dry oven		Water bath		Dry oven	
	30	60	30	60	30	60	30	60	30	60	30	60	30	60	30	60
1	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	92	90	0	0	56	68	0	0	76	68	0	0	8	4
5	100	76	96	96	76	0	92	92	0	0	92	92	0	0	88	36
6	96	88	100	96	100	100	100	96	8	0	100	96	0	0	100	88

Data taken on mold development showed that fungus activity was not arrested to any appreciable extent under any of the conditions of the experiment. Mold development was inversely proportional to the percentage of germination. It is probable that the high temperatures injured the protoplast of the seed, permitting a leaching of organic materials as was demonstrated by Hottes and Huelsen (7) in studies with sweet corn.

Unfortunately, molds had weakened the seeds in jars 1, 2, and 3 to the extent that only a few seeds germinated from jar 1 and none from jars 2 and 3 However, the temperatures used covered enough range to make this of little importance as viability was practically destroyed in No. 4 in the water bath at 70° and in the oven at 100°C. For this reason, the results from the higher moistures, while valuable, are not necessary to demonstrate the principles sought.

Table 2 shows the importance of the water content of the seed in relation to resistance to heat. One can readily see how dangerous it is to advise a farmer to heat his seed in controlling disease without giving careful thought to the water content of the grain and accurate control of temperatures.

It is evident that the method of heating is quite important. Where the seed was heated in the oven, the water content was constantly lowered throughout the period of heating. When the seed was placed in a flask with a capillary tube, there was but little change in the water content and as a result the viability was lowered much more quickly than in the oven.

The results from heating in the water bath are quite similar to those we might obtain if grain were placed in the center of a large heap as in a bin or car. Under these conditions there is little opportunity for the escape of water and the heat increases rapidly. In the same manner as illustrated in these tests, life is destroyed at lower temperatures as the water content is raised, and this temperature will be much lower than that required to destroy life when the seed is placed under the conditions obtained in an open oven.

CONCLUSIONS

1. Resistance to high temperatures is inversely proportional to the water content of the seed.
2. Seed heated in an oven or open container undergoes constant changes in water content, and this water is constantly carried off as vapor.
3. Seed heated in containers furnished with capillary tubes is subjected to a pressure near the normal, but in a humid atmosphere.
4. Recommendations to agriculturists for treatment of seeds at high temperatures for control of fungus disease should be made with extreme caution. The damage done by the heating process in presence of a moisture content fluctuating between the extremes of grain stored under varying climatic conditions may prove more destructive than the disease.

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THE EFFECT OF A SEED DISINFECTANT ON GRAIN AND STRAW YIELDS AND SMUT CONTROL IN WINTER BARLEY[1]

J. W. TAYLOR and MARION GRIFFITHS ZEHNER[2]

INTRODUCTION

The covered (*Ustilago hordei*) and loose (*U. nuda*) smuts are common in many of the fall-sown varieties of barley at the Arlington Experiment Farm, Rosslyn, Va. Data from head counts taken during the five crop seasons of 1924–1928 show an annual average of approximately 12% of covered smut and 4% of loose smut in the Tennessee Winter and Wisconsin Winter varieties grown from seed produced by apparently smut-free plants. The prevalence of the smuts of barley led to seed-treatment experiments which were begun in 1919 by Dr. G. M Reed.[3]

It was shown by Tisdale, *et al.* (1)[4] that the formaldehyde treatment was as satisfactory as the hot water method for controlling loose smut in fall-sown barley, although somewhat less satisfactory against covered smut. In later experiments Tisdale, *et al.* (2) reported more satisfactory control of both smuts, and also higher yields of the varieties, from treating the seed with commercial organic mercury seed disinfectants. As a result of these experiments one of the organic mercury compounds, Semesan, was used from 1923 to 1927, inclusive, for treating the seed of the fall-sown barleys in the varietal experiment on the Arlington farm. Four of the varieties also were grown from untreated seed in order to obtain data on the effect of the seed treatment on yields of grain and straw as well as on smut control. This paper reports the results obtained during the past five years with four fall-sown barley varieties grown from seed untreated and treated with Semesan.

METHODS AND MATERIALS

The grain from practically smut-free plants grown from treated seed of each variety was the seed used each year. The seed, contained in a cotton bag, was immersed in a 0.3% solution of Semesan for 1 hour and then spread to dry in a greenhouse. From 4 to 6 weeks elapsed between treating and seeding.

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication July 8, 1929.

[2] Associate Agronomist and Assistant Pathologist, respectively.

[3] In charge of Cereal Smut Investigations, 1919–1920, inclusive.

[4] Reference by number is to "Literature Cited", p. 123.

Both smuts occurred to some extent in the untreated plats of one or more varieties each year. The plants in the treated plats, from which seed for the next crop was to be obtained, were subjected to wind infection by loose smut from the untreated plats. There also was the opportunity of mechanical infection by covered smut, and to a lesser extent by loose smut, during threshing. The treated seed was sown before the untreated, and the crop from the treated seed was threshed before that from the untreated in order to reduce inoculation of the seed to a minimum.

The varieties grown were Wisconsin Winter, C. I. No. 2159; Tennessee Winter, C. I. No. 3543; Orel, C. I. No. 351; and Nakano Wase, C. I. No. 754. In 1928 the variety Esaw, C. I. No. 4869, was substituted for Nakano Wase. The Wisconsin and Tennessee Winter barleys are perhaps the hardiest of the fall-sown six-rowed types, but are very susceptible to both covered and loose smuts. Of all varieties grown at the Arlington Experiment Farm, the Tennessee Winter strain is the most susceptible to both smuts. Orel, a two-rowed type, generally is classed as a spring barley, but with the exception of 1928 it has been but slightly injured by winter temperatures occurring at Arlington Experiment Farm. It has been also practically free from both smuts during the past eight years.

Tisdale and Griffiths (3) have shown that Orel is highly susceptible to certain collections of loose smut when the seed is dehulled and the plants grown in the greenhouse. The resistance of Orel under field conditions may be due to the presence of the hulls, or to the absence of certain physiologic forms of smut, or to both. Nakano Wase, an awnless six-rowed type, lacks winterhardiness but has been immune from covered smut and highly resistant to loose smut. Esaw, a selection of Nakano Wase, is a high-yielding six-rowed bearded type. It has been highly resistant to covered smut but more susceptible to loose smut than Nakano Wase.

Fortieth-acre plats (132 by 8.25 feet), separated by 18-inch alleys, were used in the experiment. Two treated and two untreated plats of each variety were grown annually. The treated and untreated plats of each variety were side by side in each of the two series. In 1926, the experiment also included five eightieth-acre plats seeded with treated seed and five with untreated seed of each of the two varieties, Tennessee Winter and Nakano Wase. The treated and untreated plats of a variety were alternated in this latter experiment.

The seeding rate for all varieties was 8 pecks per acre, and the seeding was done with a single disc drill. All plats in which direct comparisons are made were seeded on the same date and harvested at one time.

All data on the percentage of the covered and loose smuts were obtained by counting the numbers of healthy heads and of heads infected with each smut in six different sections of each plat.

EXPERIMENTAL DATA

The grain yield in bushels per acre, the straw yield in pounds per acre, and the percentage of each smut in the varieties compared are given in Table 1. These figures represent the annual averages of the duplicate plats of each treatment.

CONTROL OF COVERED AND LOOSE SMUTS

The treating of fall-sown barley seed with a 0.3% solution of Semesan effectively controlled both covered and loose smuts. The 5-year average percentage of covered smut in the untreated plats of the two susceptible varieties was 12.0, as compared with a trace in the treated plats (Table 1). In the same period there was an average of 3.6% of loose smut in the untreated plats as compared with a trace in the treated.

The resistant varieties from both the treated and untreated seed were practically free of smutted plants. Esaw contained 1% of loose smut in the plat from untreated seed in 1928, as compared with a trace in that from treated seed.

EFFECT OF TREATMENT ON YIELD OF TWO SUSCEPTIBLE VARIETIES

The 5-year average grain yield of the two susceptible varieties (Tennessee Winter and Wisconsin Winter) grown from treated seed was 36.7 bushels per acre, as compared with 32.9 bushels per acre from the untreated seed. The gain in grain yield from treating was 3.8 bushels, or 11.6%.

In 4 of the 5 years of the experiment, Tennessee Winter showed an average gain from seed treatment. No significant difference in yield from treated and untreated seed of this variety was obtained in 1926 despite a total of 17.5% of loose and covered smuts present in the untreated plats. The 5-year average grain yield from treated Tennessee Winter seed was approximately 15.6% greater than the yield from the untreated seed.

Wisconsin Winter returned appreciable gains in 3 of the 5 years, *viz.*, 1924, 1927, and 1928. In 1925 and 1926 but a trace of covered smut and no loose smut occurred in this variety and the yield differences between the treated and untreated plats were small. The 5-year average gain in grain yield from seed treatment was 8.4%.

TABLE 1.—*Grain and straw yields per acre and the percentage of loose and covered smuts in susceptible and resistant varieties of barley grown from untreated and Semesan-treated seed in the 5-year period, 1924–28, inclusive, at the Arlington Experiment Farm.*

Year	Variety	C. I. No.	Treated				Untreated			
			Acre yields		Percentage of smutted heads		Acre yields		Percentage of smutted heads	
			Grain in bushels	Straw in pounds	Covered	Loose	Grain in bushels	Straw in pounds	Covered	Loose
					Susceptible					
1924	Wisconsin Winter	2159	40.8	2,126	0	0	31.1	1,598	21.7	1.3
	Tennessee Winter	3543	45.3	2,696	T	0	37.7	2,414	32.7	5.4
	Average		43.1	2,411	0	0	34.4	2,006	27.2	3.4
1925	Wisconsin Winter	2159	42.4	1,966	0	0	43.7	1,734	T	0
	Tennessee Winter	3543	32.5	1,380	0	0	24.5	1,174	7.0	T
	Average		37.5	1,673	0	0	34.1	1,454	3.5	0
1926	Wisconsin Winter	2159	43.8	1,518	0	0	45.1	1,618	T	0
	Tennessee Winter	3543	41.4	2,044	0	0	41.9	2,140	12.0	5.5
	Average		42.6	1,781	0	0	43.5	1,879	6.0	2.8
1927	Wisconsin Winter	2159	40.6	3,006	0	0.3	36.5	2,690	7.5	2.8
	Tennessee Winter	3543	19.8	1,478	0	0	17.9	1,670	15.7	5.5
	Average		30.2	2,242	0	0.2	27.2	2,180	11.6	4.2
1928	Wisconsin Winter	2159	32.2	1,614	0	T	27.9	1,564	4.4	6.6
	Tennessee Winter	3543	28.2	1,200	0	T	22.5	1,200	18.9	8.6
	Average		30.2	1,407	0	0	25.2	1,382	11.7	7.6
	Average, 1924–28		36.7	1,903	0	T	32.9	1,780	12.0	3.6
					Resistant					
1924	Orel	351	43.1	2,270	0	0	39.2	2,070	T	0
	Nakano Wase	754	27.4	1,318	0	0	28.1	1,692	0	0
	Average		35.3	1,794	0	0	33.7	1,881	0	0
1925	Orel	351	48.1	2,590	0	0	50.8	2,710	0	0
	Nakano Wase	754	23.5	1,024	0	0	10.7	540	0	0
	Average		35.8	1,807	0	0	30.8	1,625	0	0
1926	Orel	351	59.8	3,602	0	0	59.2	3,580	0	T
	Nakano Wase	754	35.5	1,588	0	T	38.7	1,412	0	T
	Average		47.7	2,595	0	0	49.0	2,496	0	0
1927	Orel	351	31.2	2,686	0	0	30.1	2,768	0	0
	Nakano Wase	754	5.4	582	0	T	2.9	562	0	T
	Average		18.3	1,634	0	0	16.5	1,665	0	0
1928	Orel	351	16.5	1,100	0	0	13.2	900	0	0
	Esaw	4869	25.0	820	0	T	26.9	948	0	1.0
	Average		20.8	960	0	0	20.1	924	0	0.5
	Average 1924–28		31.6	1,758	0	0	30.0	1,718	0	0.1

The average spring stand from treated seed of Tennessee Winter was 89.4% and from untreated seed was 88.3%. The spring stands from treated and untreated seed of Wisconsin Winter were 94.0 and 92.3%, respectively. These differences can not be considered significant.

The data obtained in the 5-year experiment permit comparisons as to the extent to which yield is reduced by covered and loose smuts. This assumes that no other seed-borne diseases influencing yield were affected by the seed treatment. Both covered and loose smuts are systemic diseases, the ingress of the smut occurring usually before emergence of the seedlings.

Plants infected with loose smut usually are taller than healthy plants. This appearance of greater height is exaggerated as the healthy heads fill and become nodding. Plants infected with covered smut are later and shorter, on an average, than the healthy heads. Little exact information is available as to the effect the smut organisms have on the vegetative growth of the barley plant. If the vegetative growth of a smutted plant is reduced or stunted early in its development, the neighboring healthy plants would benefit from the reduced competition, and yield reduction, therefore, should not be entirely proportional to infection.

In Table 1, the data show that the 5-year average increase in grain yield of the smut-susceptible varieties from treated seed was 11.6% over the yield from the untreated seed. The average percentage of covered and loose smuts in the plants from untreated seed during the same period was 15.6 The fair agreement between the percentage of smut and the difference in yield appears accidental, however, when the data are analyzed by years. Data are give for two varieties, Wisconsin Winter and Tennessee Winter, in Table 2.

TABLE 2.—*Annual percentage increase or decrease in grain yield from treated seed as compared with untreated and the increase of smutted heads in the untreated plats of two smut-susceptible winter barley varieties grown at the Arlington Experiment Farm.*

	Wisconsin Winter		Tennessee Winter	
Year	Gain or loss in percentage of grain from treated seed as compared with untreated	Percentage increase of smutted heads from untreated seed	Gain or loss in percentage of grain from treated seed as compared with untreated	Percentage increase of smutted heads from untreated seed
1924	+31.2	23.0	+20.2	38.1
1925	— 3.0	0 (t)	+32.7	7.0
1926	— 2.9	0	+ 1.2	17.5
1927	+11.2	10.0	+10.6	21.2
1928	+15.4	11.0	+25.3	27.5
Average 1924–28	+ 8.4	8.8	+15.6	22.3

With the exception of 1924, the agreement between increase in the percentage of smut in the untreated plats and the increase in grain yield from the treated plats is close in the variety Wisconsin Winter. Tennessee Winter, however, showed close agreement only in 1928. The 5-year averages of smut occurrence and grain increase in Wisconsin Winter show close agreement, but in Tennessee Winter the amount of smut is approximately 7% greater than the increased yield.

The straw yields from treated and untreated seed are given in Table 1. The average gain in straw yield from the treated seed of Wisconsin Winter and Tennessee Winter was 6.9%, as compared with 11.6% gain in grain yield. The treated seed of Wisconsin Winter produced 8.4% increase in grain yield and 11 1% increase in straw yield over those from the untreated seed. Tennessee Winter, however, had a gain of 15.6% in grain yield from treated seed but a gain of only 2.3% in straw yield. Such a slight difference in straw yields could be accounted for by the loss of chaff and awns caused by the smuts in the untreated plats.

EFFECT OF TREATMENT ON YIELD OF SMUT-RESISTANT VARIETIES

The resistant varieties, on an average, produced much less gain in grain yield after seed treatment than did the susceptible varieties. The 5-year average grain yield of the treated plats of all resistant varieties was 31.6 bushels as compared with 30.0 bushels per acre from the untreated plats, or a gain of 5.3% from treated seed. Most of the gain from treating occurred in years when the yield of the variety was poor. In 1925 and 1927, when Nakano Wase suffered severe winter injury, the treated plats decidedly outyielded the untreated plats. In 1928, Orel, which was badly winter-killed, showed a gain of 25% from treating. The 5-year average gain in grain yield from treating the seed of Orel was only slightly more than 3%. Over 14% average gain was obtained in the 4 years, 1924–27, inclusive, from treating seed of Nakano Wase, although in two of the years no gain occurred.

The average straw yields obtained from treated seed of the resistant varieties was but 2.3% greater than that obtained from untreated seed, a difference of no significance.

Tisdale and Tapke (4) found that hyphae from loose-smut spores readily enter the Nakano Wase seedling. In 1924, 50% of spike infection was obtained in Nakano Wase at Arlington Experiment Farm by floral inoculation with one strain of loose smut, but further attempts to inoculate the flowers of Nakano Wase with the same strain of inoculum failed. Tisdale and Griffiths (3) found that a high percentage of plants of both Nakano Wase and Orel died before maturity when grown from dehulled seed inoculated with loose smut

Seed of Nakano Wase, when dehulled and inoculated with covered smut, germinates poorly and abnormal seedling growth follows. In Fig. 1, two lots of seedlings of Nakano Wase are shown. The seeds of both lots were dehulled and inoculated with covered smut. The seedlings in A are from seeds which were placed in a 0.3% solution of Semesan for one hour after inoculating, while those in B were placed in tap water for the same period. The increased germination and vigor of the Semesan-treated lot are apparent. It is very probable that the seed of Nakano Wase and Orel used in these field experiments was naturally inoculated with loose smut to some extent at flowering. Inoculation with covered smut and seed coat injury in threshing also were probable.

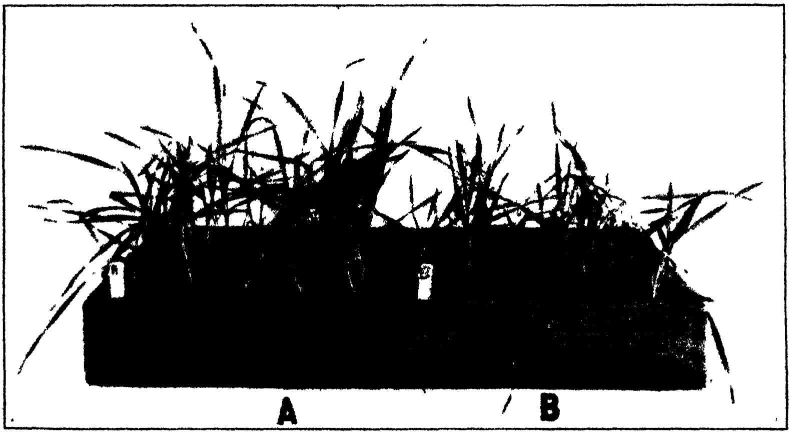

FIG. 1.—A, Seedlings from 25 seeds of Nakano Wase, dehulled, inoculated with covered smut, and soaked in a 0.3% Semesan solution for 1 hour. B, Seedlings from 25 seeds of Nakano Wase, dehulled, inoculated with covered smut, and immersed in tap water for 1 hour.

ADDITIONAL EXPERIMENTS IN 1926

Seed of Tennessee Winter and Nakano Wase, the varieties used in these experiments, was obtained from 1925 plats grown from Semesan-treated seed and which contained not over a trace of smut. The seeding date (September 28) was two days later than the seeding of the varietal plats. The productivity of the soil on which this experiment was conducted was much higher than that bearing the varietal experiment.

In Table 3 are given the individual plat yields of grain and straw and the percentages of covered and loose smuts in the replicated eightieth-acre plats of Tennessee Winter and Nakano Wase of 1926.

TABLE 3.—*Grain yield in bushels per acre and straw yields in pounds per acre and the percentage of covered and loose smuts in 80th-acre plats sown with untreated and Semesan-treated seed of two varieties of winter barley in 1926.*

	Tennessee Winter								Nakano Wase			
	Untreated				Treated				Untreated		Treated	
	Yield		Smutted heads		Yield		Smutted heads					
	Grain in bushels	Straw in pounds	Covered	Loose	Grain in bushels	Straw in pounds	Covered	Loose	Grain in bushels	Straw in pounds	Grain in bushels	Straw in pounds
			%	%			%	%				
	45.0	3,120	29	10	67.8	3,178	4	1	12.6	931	20.6	979
	35.2	2,534	30	10	52.2	2,390	4	1	18.8	1,018	18.0	960
	26.8	1,690	30	15	44.6	2,083	2	1	13.8	586	24.6	1,219
	28.8	1,978	35	6	60.6	3,043	3	1	16.0	768	18.8	826
	35.0	2,736	35	10	74.0	3,408	5	2	22.2	998	25.6	1,123
Ave.	34.2	2,412	31.8	10.2	59.8	2,820	3.6	1.2	16.7	860	21.5	1,021
Gain from treated seed					25.6	408					4.8	161
Odds					561:1	14:1					24:1	7:1

Reading from left to right and top to bottom the data for each variety are arranged in the same order as the plats occurred in the field. The untreated Tennessee Winter seed produced plants containing an average of 31.8% of covered smut and 10.2% of loose smut. The plants from the treated seed of the same variety showed 3.6% of covered smut and 1.2% of loose smut. The Semesan solution used on this seed had been used previously for treating other barley seed, and it is probable that its strength had been weakened. The difference in the combined smut percentages show 37.2 more smut in the plants from untreated seed than in those from the treated.

The average grain yield from the treated seed of Tennessee Winter was 25.6 bushels, or almost 75% more than that from the untreated seed. The fall stands on the treated plats of Tennessee Winter averaged 95% as compared with 100% on the untreated plats, but the spring stands were 90% on the treated and 88.6% on the untreated.

The straw yields of the treated plats of Tennessee Winter show a gain over those of the untreated plats of approximately 17.0%. When the yields are paired as arranged in Table 3, the difference in straw yield obtained is not significant, but pairing the straw yield of the treated plat with the average of the two untreated plats on either side changes the gain for the treated plats to 19% and increases the odds to 204:1 [5] The gains in yield of both grain and straw from treated seed of Tennessee Winter no doubt are significant.

If the percentages of smut and the spring stands recorded are fair indexes of the conditions in this experiment, it would appear that the percentage of the combined smuts present in the untreated plats of Tennessee Winter equaled approximately one-half of the reduction in grain yield In none of the nine possible comparisons of the grain yields of adjacent treated and untreated plats does the difference in the recorded percentages of smut account for the difference in the grain yield The data obtained in this experiment would indicate that the untreated seed produced some diseased plants which, though showing no smut at maturity, nevertheless were considerably reduced in grain yield, and to a lesser extent, in straw yield.

A few scattered heads of loose smut were present in both the treated and untreated plats of Nakano Wase. The average grain yield from the treated seed in the plat experiments replicated five times was approximately 29% greater than from the untreated seed. Treated seed, however, produced less than 19% more straw than

[5] The straw yield of the last treated plat is paired with the single yield of the adjacent untreated plat.

untreated seed. Neither the gain in grain yield nor straw yield shows mathematical significance, but in four of the five paired yields plants from treated seed outyielded those from untreated in both grain and straw, regardless of whether the pairings are made as arranged in the table or the yield of each plat from treated seed is paired with the average yield of the two adjacent untreated checks.

The fall stands of the plats from both treated and untreated seed averaged 98%, but the spring stands averaged only 73% from the untreated seed and 79% from the treated. It is probable that the better spring stands from the treated seed were largely responsible for any increased grain and straw yields.

SUMMARY

An excellent control of both covered and loose smuts of winter barley was obtained at the Arlington Experiment Farm, Rosslyn, Va., during the 5-year period 1924–28, inclusive, by treating seed with a commercial mercury disinfectant (Semesan). The untreated seed of the two smut-susceptible varieties produced plants having 12.0% of covered smut and 3.6% of loose smut (head count basis) as compared with a trace of each smut in those from the treated seed.

Grain yields were increased 11.6% by treating the seed of the smut-susceptible varieties.

The smut-resistant varieties produced an average increase of 5.3% in grain yield from seed treatment in the 5-year period. Most of this gain was obtained in the variety Nakano Wase, a low-yielding variety. Orel, a better adapted variety, showed no significant gain from seed treatment.

The average amount of the combined smuts in the smut-susceptible varieties was 4% greater than the percentage increase in grain yield from seed treatment. Individual years showed considerable divergence in the correlation between smut infection and the reduction in yield. In 1926, Tennessee Winter sown on Sept. 26 contained a combined total of 17.5% of smut in the untreated plats as compared with no smut in the treated plats, but no difference in grain yield was obtained. The same variety sown on Sept. 28 on a more productive soil showed 37.2% more smut in the plats from untreated seed than in those from treated seed, and the latter produced almost 75% more grain than the untreated seed.

Straw yields from the untreated seed were relatively higher than grain yields. Some reduction in straw yield, other than the loss of chaff due to loose smut, probably occurs in the smut-infected plants.

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EXPERIMENTS ON THE CONTROL OF MUSTARD[1]

Russell Bissey and O. Butler[2]

INTRODUCTION

A number of substances have been proposed for the control of mustard in grain fields and the literature upon the subject is extensive, but, as often happens with a body of evidence gathered almost exclusively from field experimentation, not a little confusing. It was thought, therefore, that it would be desirable to study comparatively under controlled conditions the various herbicides that have been used so as to determine with more precision the conditions under which they operate most effectively. Copper sulfate, iron sulfate, sulfuric acid, sodium nitrate, copper nitrate, ammonium sulfate, sodium hydroxide, sodium nitrate and copper sulfate admixed, calcium chloride, sodium bisulfate, and sodium bichromate have been used as sprays, while iron sulfate (dessicated), kainit, and cyanamide have been used as dusts.

The mustard, *Brassica arvensis* L. Ktze, used in the experiments was grown in bulb pans 25.5 cm in diameter and 9 cm deep. The seed was sown fairly heavily to insure a uniform stand, but after the plants came up they were thinned so as to give a stand of approximately one plant per square inch, that is 40 to 50 plants per pot. In the course of three to four weeks from date of sowing the plants had three to four well-developed leaves and were ready for use. When the herbicides were used as sprays in each experiment, one set of plants was dried quickly and the other slowly. The plants dried slowly were simply let stand *in situ* and, except where otherwise noted, were always dry within two hours. The plants dried slowly were placed in a moist chamber and were always wet when removed at the end of six hours. When the herbicides were used as dusts, the *modus operandi* was as follows: In one set of plants the foliage was wetted prior to the application of the dust and the plants allowed to remain *in situ;* in another set the foliage was wetted, the dust applied, and the plants removed to a moist chamber where they were held moist for six hours; and in yet another set the dust was applied to dry foliage and the plants allowed to remain *in situ*.

In the case of most of the herbicides used experiments were performed with plants grown both at a mean temperature of 12°C and a mean temperature of 18°C, these temperatures representing approximately the extremes of the range at which mustard grows naturally.

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As it was not possible to test all the herbicides used at one and the same time, in order to guard against possible errors, copper sulfate was adopted as a standard of comparison and in every experiment made a set of plants was always sprayed with this herbicide. A strict basis of comparison was therefore provided in every instance, but the variations met with during the progress of the work were not sufficiently important to warrant casting the data into relative form, and absolute numbers will be used in the tables.

EXPERIMENTAL

RESULTS WITH SPRAYS

Copper sulfate.—Copper sulfate appears to have been first used for the control of mustard coincidentally by Benard and Brandin[3] in 1897, and since then has been much employed in strengths ranging from 2 to 10%, a 4 to 5% solution being most frequently recommended. The results obtained in the present studies are shown in Table 1.

TABLE 1.—*Effect of strength of solution and rate of drying on the lethality of copper sulfate.*

Method of handling	10%		5%		2.5%		1.25%	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
			Plants Grown at 12°C					
Dried quickly	5	98.0	9	92.2	9	86.1	9	66.6
Dried slowly	5	92.0	9	87.7	9	77.7	9	61.1
			Plants Grown at 18°C					
Dried quickly	5	92.0	5	86.0	5	70.0	5	60.0
Dried slowly	5	98.0	5	94.0	5	82.0	5	70.0

The data presented show that plants grown at 12°C are injured approximately equally by quick and slow drying. This is due to the fact that even under favorable conditions plants dry rather slowly at 12°C. In the case of the experiments with copper sulfate the plants dried quickly would frequently be barely dry within a period of 2 hours; and while the data show differences in lethality due to rate of drying, these differences may be considered without significance, since in the individual experiments either quick drying or slow drying was the more lethal at all concentrations and when considered altogether there is only a majority of one in favor of quick drying. In the case of the plants grown at 18°C, quick drying caused less injury in every experiment than slow drying and the differences shown in the data must, therefore, be considered significant, if of minor importance, for within the range of effective control, 90 to 100% of the plants killed, copper sulfate is equally lethal, whether dried slowly or quickly.

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[3] Bonnet is usually credited with being the first to use copper sulfate for the destruction of mustard, but we have reason to believe (see Hitier, H. Nouveau procédé de destruction de la moutarde souvage. Jour. Agr. Prat., 1; 704–706. 1897.) that he used in his experiments a 6% acid bordeaux mixture and not copper sulfate.

It may be concluded from the data presented that a 10% solution of copper sulfate is stronger than actually needed for the control of mustard and that a 2.5% solution is the minimum strength that could be recommended for use even under favorable conditions.

Iron sulfate.—Iron sulfate has been used with success for the control of mustard in grain fields at strengths varying from 10 to 30%. In the authors' experiments, the maximum strength used was 25%, the concentration most commonly recommended, and the minimum 3%, which is well below the range used in practice. The results obtained are summarized in Table 2.

TABLE 2.—*Effect of strength of solution and rate of drying on the lethality of iron sulfate.*

Method of handling	2.5%		12.5%		6%		3%	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
	Plants Grown at 12°C							
Dried quickly.	7	94.0	7	84.3	2	75.0	2	70.0
Dried slowly.	7	94.0	7	87.0	2	75.0	2	65.0
	Plants Grown at 18°C							
Dried quickly..	4	85.0	4	77.5	4	67.5	4	55.0
Dried slowly...	4	100.0	4	95.0	4	85.0	4	67.5

The data show that when iron sulfate is applied to plants growing at a mean temperature of 12°C the rate of drying does not materially affect the degree of injury produced, but that when the herbicide is applied to plants growing at 18°C quick drying is much less effective than slow drying. The mean temperature under which the sprayed plants are grown influences, therefore, rather markedly the herbicidal properties of iron sulfate and virtually limits to 25% the strength at which this substance can be safely recommended for use in the control of mustard.

Sulfuric acid.—First used in 1897 by Duclos, sulfuric acid has become more and more generally used as an herbicide. Aslander, in particular, has carefully studied the effect of concentration on lethality and the relation of the milieu to lethality. The results obtained in the present studies are given in Table 3. A glance at the table shows that the herbicidal properties of sulfuric acid are not affected by the temperature at which the sprayed plants are grown nor by the rate of drying.

TABLE 3.—*Effect of strength of solution and rate of drying on the lethality of sulfuric acid.*

Method of handling	10% by weight No. of tests	10% by weight Plants killed %	5% by weight No. of tests	5% by weight Plants killed %	2.5% by weight No. of tests	2.5% by weight Plants killed %	1.25% by weight No. of tests	1.25% by weight Plants killed %
Plants Grown at 12°C								
Dried quickly	2	100	5	100	5	92	5	76
Dried slowly	2	100	5	95	5	88	5	70
Plants Grown at 18°C								
Dried quickly	1	100	2	100	2	95	2	85
Dried slowly	1	100	2	100	2	90	2	80

Most herbicides kill the leaves of mustard without directly injuring the petioles and stems, the death of these parts following as a result of the injury to the former but not concomitantly. In the case of sulfuric acid, however, when the concentration used is sufficient to cause death, the mortality of all parts is synchronous, the plants withering and falling flaccid upon the ground (See Fig. 1.)

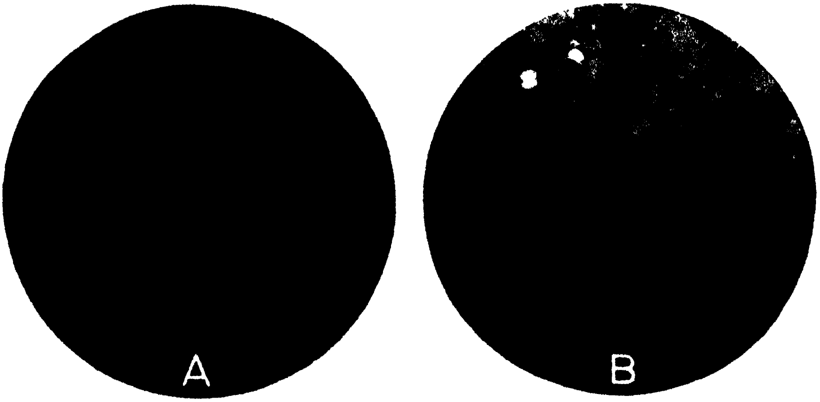

FIG. 1.—A, mustard sprayed with a 5% solution of sulfuric acid and dried slowly. Photograph taken 3 days after treatment. B, stand and stage of development of untreated mustard 3 days after the sulfuric acid was applied.

Copper nitrate.—Copper nitrate has not been extensively used as an herbicide. Duclos in 1897 found a 1.25% solution very effective for the control of mustard. Dusserre, who also used it, ventures the opinion that a 2% solution of copper nitrate is approximately equal to a 3% solution of copper sulfate. The results obtained by the authors are summarized in Table 4 and show that copper nitrate ($Cu(NO_3)_2.3H_2O$) is an active herbicide (Fig. 2A) and is more lethal dried quickly than dried slowly, particularly when applied to plants grown at 12°C.

TABLE 4.—*Effect of strength of solution and rate of drying on the lethality of copper nitrate.*

Method of handling	5%		2.5%		1.25%		0.6%	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
			Plants Grown at 12°C					
Dried quickly	4	95	4	90	4	82	1	70
Dried slowly	4	85	4	77	4	65	1	60
			Plants Grown at 18°C					
Dried quickly	3	100	3	100	2	95	2	85
Dried slowly	3	100	3	100	2	90	2	80

Copper nitrate, weight for weight, is much more active than copper sulfate. At the lowest concentration used, 0.6%, it is three times more active and at the highest concentration twice as active.

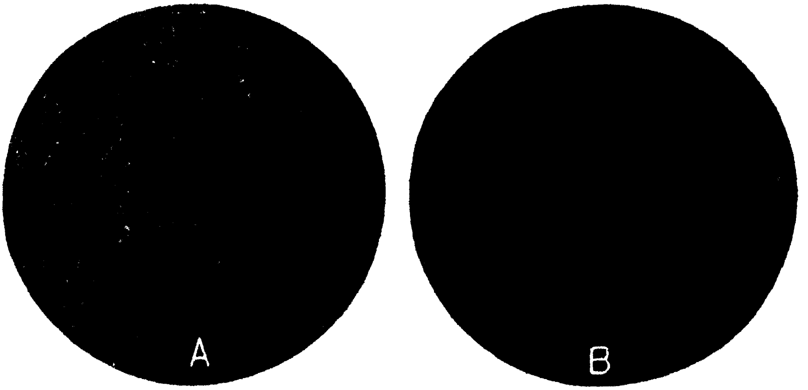

FIG. 2.—A, mustard sprayed with a 2.5% solution of copper nitrate and dried quickly. Photograph taken 3 days after treatment. See Fig. 1 B for appearance of untreated mustard at the time this photograph was taken. B, Mustard sprayed with a 2.5% solution of sodium bichromate and dried quickly. The oats in the pot, which were not affected by the treatment, were cut off before the photograph was taken so as to show clearly how thoroughly the mustard had been destroyed. Photograph taken 3 days after treatment. See Fig. 1 B for appearance of untreated mustard at the time this photograph was taken.

Sodium hydroxide.—Solutions of the soluble alkalies are injurious to foliage and it was thought that sodium hydroxide might effectively control mustard at relatively low concentrations. The results obtained with plants grown at 12°C are presented in Table 5. The data clearly show that sodium hydroxide is not effective when used at a lesser concentration than 5%.

TABLE 5.—*Effect of strength of solution and rate of drying on the lethality of sodium hydroxide.*

Method of drying	10%		5%		2.5%		1.25%	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
Dried quickly .	4	100	4	95	4	65	4	52
Dried slowly . . .	4	97	4	85	4	60	4	50

Ammonium sulfate.—Ammonium sulfate has been used to some extent for the control of mustard at strengths varying from 25 to 33%. In our experiments, as will be seen from a consideration of the data presented in Table 6, it was not found very effective. It will be noticed also that plants grown at 18°C are much more easily killed by ammonium sulfate than plants grown at 12°C.

TABLE 6.—*Effect of strength of solution and rate of drying on the lethality of ammonium sulfate.*

Method of handling	40%		20%		10%		5%	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
		Plants Grown at 12°C						
Dried quickly.	3	83	3	63	3	60	–	—
Dried slowly	3	70	3	56	3	53	–	—
		Plants Grown at 18°C						
Dried quickly	–	—	2	95	2	80	2	65
Dried slowly.	–	—	2	85	2	70	2	55

Sodium nitrate.—Sodium nitrate has been used to some extent for the control of mustard, but it was not found as effective even as ammonium sulfate. Sodium nitrate is more effective dried slowly than dried quickly and plants grown at 12°C are quite distinctly less sensitive than plants grown at 18°C On the average, less than 75% of the plants grown at 12°C are killed by spraying with a 50% solution, but it only requires a 20% solution to cause a like mortality when the plants are grown at 18°C.

Sodium nitrate and copper sulfate.—Sodium nitrate and copper sulfate mixed together have been used for the control of mustard and, according to Brenchley, the presence of the former increases the effectiveness of the latter. The data presented in Table 7 show that sodium nitrate and copper sulfate mixed together in the ratio of 4 to 1 make an excellent herbicide. The addition of sodium nitrate to the weaker concentrations of copper sulfate materially increased the herbicidal properties of the latter, in round numbers the increase in effectiveness due to the addition of the saltpeter being 2. A 2.5% copper sulfate in 10% sodium nitrate is as effective as a 5% solution of copper sulfate. The plants were grown at 18°C.

TABLE 7.—*Effect of strength of solutions and rate of drying on the lethality of sodium nitrate and copper sulfate mixed in the ratio of 4 to 1.*

Method of drying	5%*		2.5%*		1.25%*	
	No. of tests	Plants killed %	No. of tests	Plants killed %	No. of tests	Plants killed %
Dried quickly.	5	100	5	96	5	76
Dried slowly	5	98	5	92	5	74

*Strength of the solution in per cent of copper sulfate.

Sodium bichromate.—In the experiments made with sodium bichromate the plants sprayed were grown at a mean temperature of 18°C and the results obtained are summarized in Table 8. The data show that sodium bichromate is not materially affected by the rate of drying and possesses herbicidal properties that place it in the same category as sulfuric acid, which it also resembles in its mode of action on plants (Fig. 2 B).

TABLE 8.—*Effect of strength of solution and rate of drying on the lethality of sodium bichromate.*

Method of drying	10% No. of tests	10% Plants killed %	5% No. of tests	5% Plants killed %	2.5% No. of tests	2.5% Plants killed %	1.25% No. of tests	1.25% Plants killed %
Dried quickly . .	1	100	3	100	3	93.3	3	80.0
Dried slowly . . .	1	100	3	100	3	96.6	3	83.3

Sodium bisulfate.—Sodium bisulfate has been but little used as an herbicide, but as will be seen from the data presented in Table 9, it is not one whit inferior to copper sulfate and is even less affected than the latter by rate of drying. In its effect upon the sprayed plant, sodium bisulfate resembles sulfuric acid (Fig. 3 A).

TABLE 9.—*Effect of strength of solution and rate of drying on the lethality of sodium bisulfate.*

Method of handling*	10% No. of tests	10% Plants killed	5% No. of tests	5% Plants killed %	2.5% No. of tests	2.5% Plants killed %	1.25% No. of tests	1.25% Plants killed %
Dried quickly	2	100	3	96.6	3	80.0	1	70.0
Dried slowly	2	100	3	96.6	3	80.0	1	70.0

*Plants grown at 18°C.

Calcium chloride.—Mustard plants growing at 12°C were sprayed with calcium chloride ($CaCl_2.H_2O$), but the salt was not lethal even when used at a strength of 50%.

RESULTS WITH DUSTS

Kainit.—Kainit has been used for the control of mustard in amounts varying from 640 to 2,600 pounds per acre and the results secured have been sufficiently gratifying to warrant further study of this material. The kainit[4] used in these tests was ground to pass a 65-mesh sieve and was applied at a rate equivalent to 640 pounds per acre in a series of four experiments, the mean data for which are presented in Table 10. It will be noted that when Kainit was applied to wet foliage the number of plants destroyed was not materially affected by the rate of drying, the control obtained being adequate under both durations employed, but that satisfactory control was not secured when the material was applied to dry foliage (Fig. 3 B).

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[4] We have to thank S. D. Gray of N. V. Potash Export My., New York, who supplied the material used.

TABLE 10.—*Effect of wetness of foliage and rate of drying on the lethality of kainit.*

Condition of foliage when dusted	Plants killed %
Wet, dried quickly	82
Wet, dried slowly	85
Dry	70

An experiment was also made using in one case plants growing at 12°C and in the other plants growing at 18°C for the purpose of determining the minimum amount of kainit required for adequate control. The plants were dusted with the equivalent of 640, 320, and 160 pounds per acre. Adequate control was obtained only with the amount equivalent to 640 pounds per acre.

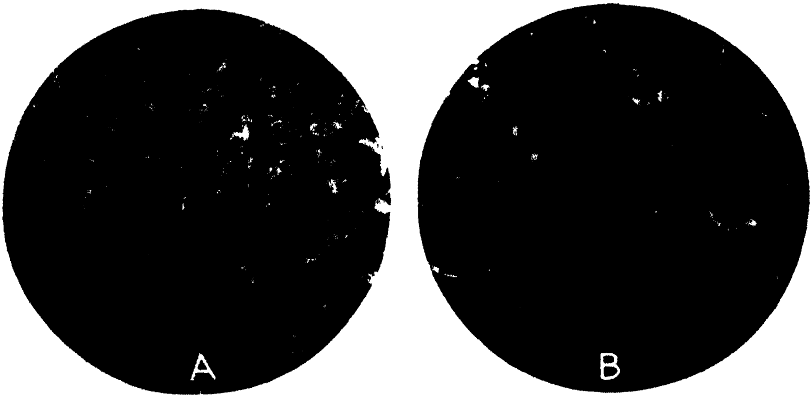

FIG. 3.—A, mustard sprayed with a 5% solution of sodium bisulfate and dried quickly. Photograph taken 3 days after treatment. See Fig. 1 B for appearance of untreated mustard at the time this photograph was taken. B, mustard sprayed with water and then dusted with an equivalent of 480 pounds of finely ground kainit per acre. The oats in the pot, which were not affected by the treatment, were cut off before this photograph was taken so as to show clearly the extent of injury to the mustard. The photograph was taken 8 days after treatment. See Fig. 4 A for appearance of untreated mustard at the time this photograph was taken.

Calcium cyanamide.—Calcium cyanamide has been used for the control of mustard and the results obtained (Table 11) show that it gives excellent control of this weed when applied to moist foliage (Fig. 4). The data given are the mean of four experiments with plants grown at 12°C and the cyanamide was applied as received from the manufacturer[5] at a rate equivalent to 320 pounds per acre. As an application of 320 pounds per acre of cyanamide is a large amount of nitrogenous fertilizer to use, an experiment was also made with plants growing at 12°C and 18°C for the purpose of studying the control obtainable with lesser amounts. The equivalent of 80 pounds per acre applied to wet foliage killed 80% of the mustard.

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[5] The cyanamide used was furnished by the American Cyanamide Co.

TABLE 11.—*Effect of wetness of foliage and rate of drying on the lethality of cyanamide.*

Condition of foliage when dusted	Plants killed %
Wet, dried quickly	87
Wet, dried slowly	90
Dry	70

Iron sulfate dust.—Dry iron sulfate ($FeSO_4$) has been used in Europe for the control of mustard. Applied at a rate equivalent to 400 pounds per acre to plants growing at 12°C, the control obtained (Table 12) is more affected by the condition of the leaves at the time of and subsequent to the application than is the control obtained with kainit and cyanamide. Applied to wet leaves and dried quickly, the iron sulfate was less effective than when applied to wet leaves and dried slowly and was ineffective when dusted on dry leaves.

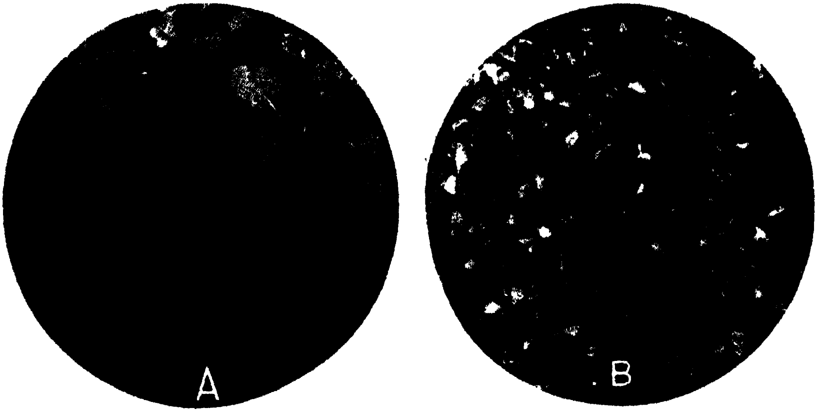

FIG. 4.—A, stand and stage of development of untreated mustard 8 days after kainit was applied. B, mustard showing extent of injury produced by dusting dry foliage with the equivalent of 320 pounds of calcium cyanamide per acre. Photograph taken 8 days after treatment. A shows the appearance of untreated mustard at the time this photograph was taken.

When iron sulfate is used as a spray, it will be remembered that a 25% solution gave adequate control, whether the plants were dried quickly or slowly. If we assume that, in spraying, 100 gallons of solution are applied per acre, which is a liberal allowance, then control is obtained by the use of 200 pounds of iron sulfate per acre. When used in the dry form and as a dust, it has just been shown that 400 pounds are not completely effective. Iron sulfate dust can not, therefore, be considered as a substitute for iron sulfate spray. As an herbicide for the control of mustard it has no right to be.

TABLE 12.—*Effect of wetness of foliage and rate of drying on the lethality of iron sulfate as a dust.*

Condition of foliage when dusted	Plants killed %
Wet, dried quickly	77
Wet, dried slowly	82
Dry	62

CONCLUSIONS

The herbicides applied as sprays in the present study, with the exception of sodium nitrate and ammonium sulfate, show approximately the same degree of lethality for a given strength, whether applied to plants grown at a mean temperature of 12° or 18°C. Sodium nitrate and ammonium sulfate, on the other hand, when used at a strength destructive to plants grown at 18°C are relatively inocuous to plants grown at 12°C.

The rate at which the herbicides used as sprays are dried does not materially affect their toxicity, except in the case of iron sulfate which is approximately twice as active dried slowly as when dried quickly.

In practice, a high degree of toxicity per unit weight is desirable The herbicides used as sprays destroyed 90% of the mustard when used at the strengths indicated below, the substances being listed in decreasing order and assuming average conditions:

Copper nitrate	1 %
Sodium bichromate	1 8%
Sulfuric acid	2.2%
Copper sulfate in 10% sodium nitrate	2.5%
Sodium bisulfate	3.8%
Copper sulfate Sodium hydroxide	5 %
Iron sulfate	15 %
Ammonium sulfate	20 %
Sodium nitrate	over 20 %

The figures show that copper sulfate occurs in a group of substances in which the toxic equivalent is rather close and ranges from 1 to 5, but that iron sulfate occupies a low position in the scale.

It has been pointed out that the toxicity of sodium nitrate and ammonium sulfate is affected by the temperature at which the sprayed plants were grown and that the toxicity of iron sulfate is markedly affected by the rate of drying. When we add further that these three substances possess a low toxic value per unit weight, their retention on a list of herbicides useful for the control of mustard seems no longer desirable.

If we assume that the substances possessing a toxic equivalent of 1 to 5 are all equally satisfactory as herbicides, then a selection from this group will be based upon relative cost, ease of handling, and corrosion of spray machinery. The substances in the group mentioned are not equally corrosive. A bright steel nail partially immersed in them for 6 minutes at room temperature showed the following reaction upon being withdrawn:

5 % copper sulfate	deep etching
2.2% sulfuric acid	very slight etching
1 % copper nitrate	no visible effect
1.6% copper sulfate in 6.4% sodium nitrate	no visible effect
3.8% sodium bisulfate	no visible effect
1.8% sodium bichromate	no visible effect

Four of the sprays most effective for the control of mustard have little or no action on iron. Copper nitrate is too expensive to be given serious consideration at the present time, but copper sulfate and sodium nitrate mixed, sodium bisulfate, and sodium bichromate should be given extensive field trials.

With the exception of iron sulfate, the dusts used in the experiments proved very effective. Weight for weight, cyanamide is eight times as effective as kainit ground to pass a 65-mesh sieve, but as it is a nitrogenous fertilizer its use for the control of mustard in oats is generally inappropriate. Kainit, on the other hand, is a potash fertilizer and oats do not lodge following its use. Both kainit and cyanamide must be applied to wetted foliage, but after they have been applied, the rate at which the leaves dry is not important.

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EFFECT OF SOIL TYPE AND FERTILIZER TREATMENT ON THE COMPOSITION OF THE SOYBEAN PLANT[1]

Russell H. Austin[2]

The value of the soybean plant for hay is dependent upon the composition of the plant. If the plant has not had access to sufficient amounts of the essential elements of plant food and is deficient in one or more of the essential elements, its feeding value is less than it would have been normally. A deficiency in the supply of phosphorus or of calcium and phosphorus in the soil available to soybeans has resulted in ill effects upon the cattle consuming the plants as hay or as pasture. The hay grown on soils decidedly low in available phosphorus is itself low in phosphorus in comparison with hay grown on soils of an average or high content of available phosphorus.

PLAN OF EXPERIMENT

FIELD EXPERIMENTS

Fertilizer tests with soybeans were conducted in the field on five soil types common to Michigan, including Brookston clay loam near Chesaning, Coloma sand and Kewanee loam near Lowell, Fox sandy loam on the Cass County farm near Cassopolis, and Miami loam near Mason. In addition to these projects, an unfertilized plat was located on Hillsdale sandy loam on the College farm at East Lansing. The purpose of the unfertilized plat was to furnish samples for a more detailed study of the changes in the composition of the soybean plant during the growing season.

The fertilizer treatments were as follows:

Brookston clay loam, Chesaning.

Plat No.	Pounds per acre			
	Superphosphate*	Gypsum†	KCl	$NaNO_3$‡
1	No treatment	——	——	——
2	400	200	100	100
3	250	——	——	——
4	250	200	——	——
5	250	200	100	——
6	250	200	100	100
7	800	200	100	100

*Anaconda phosphate was used in amounts equivalent to superphosphate.
†Sulfur was used in amounts equivalent to the gypsum.
‡Urea was used in amounts equivalent to the sodium nitrate.

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[1] Contribution from the Soils Section, Michigan State College, East Lansing, Mich. A part of thesis presented to the Michigan State College in partial fulfillment of the requirement for the degree of doctor of philosophy. Received for publication July 29, 1929.

[2] Formerly Graduate Assistant in Soils, Michigan State College; now Assistant Professor of Agronomy, College of Agriculture, University of Tennessee. The writer wishes to take this opportunity to express his appreciation to Dr. McCool of the Soils Section, Michigan State College, for his kindly interest and helpful suggestions.

Fertilizer treatment on Coloma sand, Lowell

Plat No.	Calcic lime	Magnesic lime	Pounds per acre Superphosphate*	Gypsum	KCl	$NaNO_3$†
1	No treatment	—	—	—	—	—
2	5,000	—	—	—	—	—
3	—	5,000	—	—	—	—
4	—	5,000	250	—	—	—
5	—	5,000	250	200	—	—
6	—	5,000	250	200	100	—
7	—	5,000	250	200	100	100

*Anaconda phosphate was used in amounts equivalent to superphosphate.
†Urea was used in amounts equivalent to the nitrate of soda.

Fox sandy loam, Cassopolis.

Plat No.	Calcic lime	Superphosphate	Pounds per acre Gypsum	KCl	$NaNO_3$	Rock phosphate
1	No treatment	—	—	—	—	—
2	6,300	—	—	—	—	—
5	6,300	200	86*	—	—	—
6	6,300	200	86*	100	—	—
7	6,300	200	86*	100	100	—
2a	6,300	—	—	100	—	—
3a	6,300	—	86	—	—	1,000
4a	6,300	—	—	—	—	1,000
8a	6,300	—	—	—	100	—
8c	6,300	—	—	100	100	—
9a	6,300	200	86*	—	100	—

*Gypsum in the 200 pounds superphosphate application.

The fertilizer treatments on Kewanee loam were the same as those on Coloma sand, with the exception of the lime treatments, which were 3,000 pounds on Kewanee loam The treatments on Miami loam were the same as those on Coloma sand

GREENHOUSE EXPERIMENTS

Some studies of the effect of soil type and fertilizer treatments upon the composition of the cell sap were made upon samples taken from the field plats. In addition, tests were conducted in the greenhouse with soybeans in pots of 2-gallon capacity. Soils for these tests were collected from tilled areas of Coloma sand, Fox sandy loam, Berrien sandy loam, Nappanee loam, Miami loam, and Kalamazoo muck. Nitrate of soda was applied to all pots in sufficient amount to care for the needs of the plants for nitrogen. The phosphorus and potassium treatments for the pots were as follows:

Pot No.	Grams per pot $CaH_4(PO_4)_2$	KCl
1	None	None
2	0.2	0.1
3	2.0	1.0

METHODS OF ANALYSIS

The ash, total nitrogen, calcium, magnesium, sulfur, and phosphorus of the soybean plant were determined by the official methods of the Association of Official Agricultural Chemists (Ed. 2, 1924). Potassium in the plant and cell sap was determined by the cobaltinitrate method of Adie and Wood.[3] The phosphorus of the cell sap was determined by the coeruleo-molybdate reaction of Deniges,[4] and calcium by the official method.

VARIATIONS IN THE COMPOSITION OF THE SOYBEAN DURING GROWTH

Small variations in the composition of soybean plants during growth were noted on both the fertilized and unfertilized soils. Many of these variations, however, though small numerically, are appreciably large.

The ash content of the soybean plant was greater in many cases 73 days after seeding than it was either 35 or 110 days after seeding. This increase was greatest in the plants grown on Coloma sand (Table 3) receiving either calcic lime or magnesic lime. In most instances, however, the ash content was greater in the plants 35 days after seeding than it was 73 days after seeding. In every case the ash content of the plants was lowest 110 days after seeding for each soil and for each fertilizer treatment. By this time, the plants have larger amounts of the carbohydrates, proteins, etc., than in the earlier stages of growth.

The calcium content, as a whole, decreased with the age of the plants. The plants grown on Coloma sand (Table 3) receiving no fertilizer or receiving calcic lime alone had a higher calcium content 110 days after seeding than they had 73 days after seeding.

The magnesium content was not as uniform as the calcium content. However, a general decrease in the magnesium content of the plants occurred as they grew older. Less difference occurred between the plants on the different soils for the period from 73 days to 110 days after seeding than for the period from 35 to 73 days after seeding.

The nitrogen content of the plants showed a general decrease with the age of the plants. However, the nitrogen content of the plants on Coloma sand (Table 3) on all plats increased during the period from 73 to 110 days after seeding.

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[3] ADIE, R. H., and WOOD, T. B. A new method of estimating potassium. Jour. Chem. Soc., T., 1076: 17. 1900.

[4] ATKINS, W. R. G. The rapid determination of available phosphate in soils by the coeruleo-molybdate reaction of Deniges. Jour. Agr. Sci., 14: 192. 1924.

TABLE 1.—*Analysis based on dry weight of soybeans on Hillsdale sandy loam, unfertilized, East Lansing.*

Days after seeding	Ash %	Ca %	Mg %	N %	S %	P %	K %
30	10.70	2.702	0.586	4.414	0.232	0.234	0.695
41	10.97	2.801	0.756	4.414	0.253	0.331	0.677
52	12.53	2.547	0.923	4.542	0.277	0.329	0.775
62	10.54	2.415	0.893	4.423	0.277	0.316	0.626
72	9.23	2.050	0.846	3.833	0.283	0.287	0.722
83	8.19	1.879	0.780	3.349	0.265	0.272	0.609
93	8.27	1.905	0.756	3.219	0.251	0.287	0.726
104	8.13	1.865	0.719	3.167	0.249	0.329	0.576

TABLE 2.—*Analysis based on dry weight of soybeans on Brookston clay loam, Chesaning.*

Sample No.	Treatment in pounds per acre	Ash %	Ca %	Mg %	N %	S %	P %	K %
A—35 days after seeding (July 15)								
111	none	9.72	2,162	1.083	4.815	0.289	0.469	0.635
112	400—P S K N	9.67	2.345	1.230	4.523	0.300	0.440	0.584
113	250—P	10.00	2.282	1.376	3.914	0.280	0.335	0.579
114	250—P S	9.57	2.265	1.366	4.057	0.291	0.372	0.600
115	250—P S K	9.98	2.242	1.352	4.221	0.250	0.363	0.711
116	250—P S K N	10.27	2.311	1.394	4.097	0.269	0.360	0.692
117	800—P S K N	10.30	2.227	1.343	4.032	0.282	0.395	0.701
B—71 days after seeding (Aug. 20)								
151	none	10.61	1.792	1.086	3.463	0.291	0.374	0.627
152	400—P S K N	11.28	1.809	1.105	3.514	0.307	0.375	0.561
153	250—P	8.96	1.739	1.026	2.544	0.291	0.291	0.631
154	250—P S	9.38	1.954	1.066	2.366	0.294	0.282	0.569
155	250—P S K	9.24	1.726	0.965	2.771	0.280	0.247	0.621
156	250—P S K N	9.01	1.874	0.976	2.725	0.283	0.243	0.612
157	800—P S K N	10.75	1.822	1.017	2.847	0.286	0.376	0.659
C—110 days after seeding (Sept. 26)								
181	none	8.56	1.581	0.795	2.291	0.326	0.390	0.713
182	400—P S K N	8.82	1.610	0.884	2.316	0.296	0.394	0.634
183	250—P	7.06	1.724	1.061	1.595	0.365	0.329	0.555
184	250—P S	9.00	1.993	1.004	1.645	0.418	0.329	0.556
185	250—P S K	8.72	1.746	0.911	2.004	0.331	0.318	0.635
186	250—P S K N	8.07	1.766	1.065	1.610	0.289	0.290	0.592
187	800—P S K N	8.36	1.817	1.096	1.823	0.379	0.428	0.754

TABLE 3.—*Analysis based on dry weight of soybeans on Coloma sand, Lowell.*

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
A—35 days after seeding (July 16)								
211	none	10.12	2.799	0.694	4.173	0.318	0.411	0.504
212	Ca-lime	9.73	2.162	0.824	3.432	0.377	0.427	0.532
213	Mg-lime	9.06	1.993	0.815	3.393	0.293	0.297	0.488
214	*Mg P	10.38	2.603	0.884	3.883	0.377	0.451	0.656
215	*Mg P S	10.70	2.428	1.008	3.676	0.451	0.407	0.596
216	*Mg P S K	10.66	1.957	0.729	3.405	0.398	0.390	0.816
217	*Mg P S K N	10.79	1.815	0.742	3.996	0.288	0.318	0.813
B—73 days after seeding (Aug. 23)								
251	none	11.38	1.760	0.664	2.163	0.321	0.403	0.729
252	Ca-lime	14.83	1.754	0.575	1.973	0.326	0.404	0.629
253	Mg-lime	11.53	1.766	0.960	1.800	0.393	0.416	0.727
254	*Mg P	9.05	2.036	0.928	1.889	0.361	0.392	0.784
255	*Mg P S	9.11	2.036	1.007	1.548	0.385	0.397	0.798
256	*Mg P S K	8.30	1.633	0.629	1.422	0.345	0.409	0.835
257	*Mg P S K N	7.69	1.486	0.585	1.566	0.243	0.302	0.692

TABLE 3.—*Concluded.*

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
C—109 days after seeding (Sept. 27)								
281	none	8.37	2.115	0.607	2.441	0.386	0.462	0.591
282	Ca-lime	8.15	2.080	0.457	2.324	0.420	0.477	0.548
283	Mg-lime	8.12	1.173	1.035	2.708	0.536	0.509	0.647
284	*Mg P	8.09	1.406	0.787	2.308	0.518	0.490	0.518
285	*Mg P S	7.50	1.428	0.785	2.139	0.476	0.451	0.641
286	*Mg P S K	9.04	1.414	0.800	2.119	0.503	0.547	0.698
287	*Mg P S K N	7.56	1.336	0.590	1.818	0.379	0.489	0.723

*Magnesic lime.

TABLE 4.—*Analysis based on dry weight of soybeans on Kewanee loam, Lowell.*

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
A—35 days after seeding (July 16)								
311	none	9.87	2.081	0.663	5.063	0.275	0.345	0.812
312	Ca-lime	10.22	2.290	0.802	5.089	0.282	0.346	0.653
313	Mg-lime	10.39	2.210	0.800	5.059	0.279	0.340	0.690
314	*Mg P	10.78	2.256	0.843	5.076	0.272	0.340	0.764
315	*Mg P S	10.37	2.007	0.754	5.323	0.284	0.364	0.843
316	*Mg P S K	11.05	1.990	0.723	4.783	0.270	0.325	0.774
317	*Mg P S K N	11.26	1.906	0.688	4.833	0.279	0.356	0.835
B—73 days after seeding (Aug. 23)								
351	none	9.41	1.813	0.643	3.556	0.236	0.383	0.623
352	Ca-lime	9.73	1.812	0.644	3.678	0.253	0.270	0.717
353	Mg-lime	10.25	1.710	0.702	3.901	0.275	0.289	0.721
354	*Mg P	9.02	1.814	0.732	3.658	0.274	0.308	0.703
355	*Mg P S	9.86	1.719	0.648	3.722	0.304	0.349	0.817
356	*Mg P S K	9.63	1.814	0.733	3.422	0.284	0.331	0.757
357	*Mg P S K N	9.74	1.765	0.782	3.910	0.285	0.322	0.703
C—109 days after seeding (Sept. 27)								
381	none	6.92	1.294	0.536	3.528	0.277	0.423	0.738
382	Ca-lime	6.93	1.187	0.522	3.424	0.260	0.390	0.776
383	Mg-lime	6.48	1.418	0.672	3.103	0.282	0.357	0.728
384	*Mg P	6.40	1.362	0.624	3.028	0.258	0.374	0.688
385	*Mg P S	6.66	1.210	0.509	3.147	0.257	0.376	0.678
386	*Mg P S K	6.32	1.260	0.513	3.449	0.270	0.388	0.794
387	*Mg P S K N	6.37	1.239	0.530	3.351	0.251	0.365	0.693

*Magnesic lime.

TABLE 5.—*Analysis based on dry weight of soybeans on Miami loam, Mason.*

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
A—36 days after seeding (July 14)								
511	none	9.46	2.370	0.832	4.977	0.258	0.312	0.663
512	Ca-lime	9.34	2.049	0.820	4.781	0.262	0.278	0.795
513	Mg-lime	9.06	2.167	0.842	4.740	0.243	0.246	0.745
514	*Mg P	9.03	2.112	0.910	4.633	0.245	0.273	0.661
515	*Mg P S	9.09	2.333	0.894	4.510	0.247	0.265	0.592
516	*Mg P S K	8.96	2.115	0.836	4.545	0.238	0.250	0.654
517	*Mg P S K N	9.30	2.300	0.908	4.768	0.248	0.258	0.668
B—73 days after seeding (Aug. 19)								
551	none	8.58	1.834	0.773	4.023	0.260	0.242	0.774
552	Ca-lime	8.39	1.691	0.781	3.851	0.251	0.226	0.778
553	Mg-lime	8.70	1.787	0.744	4.054	0.268	0.234	0.684
554	*Mg P	8.83	1.739	0.873	3.788	0.264	0.235	0.725
555	*Mg P S	8.73	1.869	0.940	3.801	0.272	0.265	0.666
556	*Mg P S K	9.38	1.851	0.882	3.677	0.260	0.256	0.710
557	*Mg P S K N	8.71	1.707	0.777	3.458	0.274	0.261	0.758

TABLE 5.—*Concluded*

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
		C—111 days after seeding (Sept. 26)						
581	none	6.29	1.291	0.637	3.277	0.229	0.280	0.532
582	Ca-lime	6.13	1.183	0.552	3.570	0.241	0.273	0.596
583	Mg-lime	6.44	0.943	0.494	3.697	0.263	0.285	0.575
584	*Mg P	6.23	1.173	0.682	2.910	0.243	0.285	0.540
585	*Mg P S	5.97	1.193	0.752	3.437	0.240	0.322	0.510
586	*Mg P S K	6.48	1.159	0.629	3.750	0.255	0.352	0.555
587	*Mg P S K N	6.52	1.278	0.733	3.578	0.226	0.305	0.570

*Magnesic lime.

The sulfur content was the most uniform of all the elements studied in these experiments, especially in the plants receiving no fertilizer and complete fertilizer. The only variation of any significance was in the plants on Coloma sand (Table 3). Here, all fertilizer treatments increased the sulfur content of the plants in the latter half of the period of growth but decreased it in the first half of the period of growth, with the one exception of the treatment of magnesic lime on plat 3.

The phosphorus content was lower 73 days after seeding than it was at either the 35th or 110th day after seeding. On Kewanee loam the phosphorus content of the unfertilized plants was found to have increased with the age of the plants (Table 4). This increase in the phosphorus content was greatest in the plants on Coloma sand receiving magnesic lime (Table 3). The phosphorus content of the plants on the unfertilized Hillsdale sandy loam (Table 1), which was sampled at 10- or 11-day intervals, increased a small amount in the second sample (41 days after seeding) and then decreased, though to a less degree, to and including the sixth sample (83 days after seeding). It increased again in the eighth sample (104 days after seeding). The results of these experiments suggest a tendency for the phosphorus content of the soybean plants to increase during the latter half of the growing season.

The potassium content was the most irregular of the elements studied in these experiments, but the majority of the variations were small. Some of the largest variations were increases occurring with the growth of the plants during the period of 35 to 73 days after seeding on Coloma sand receiving no fertilizer, magnesic lime alone, and a treatment of magnesic lime, phosphorus, and sulfur. The general tendency seemed to be toward a small increased potassium content when the plants were half grown and a decrease in the plants when older.

The results obtained in these experiments show that the content of ash, calcium, and magnesium decreased with the age of the plants.

In the sulfur content there was a striking uniformity throughout the growth of the plant except in the case of those plants grown on Coloma sand. In those plants receiving fertilizers there was a small decrease in the first half of the season and an increase in the latter part of the season of growth. The nitrogen content of the plants on Coloma sand was an exception to the general results obtained. In general, there was a decrease in the nitrogen content with the age of the plants. It is possible the increase which occurred in the plants on Coloma sand was due to the inefficient utilization by the plants of the elements available in an unbalanced proportion. This is logical, for plants do include in their structure appreciably large amounts of some elements not now known to be of any definite value to them. The selective feeding ability of the plant is exceeded by the unbalanced proportions of available elements in some cases. The function of phosphorus in the plant has been considered one closely associated with the maturity and fruiting of the plant. The higher content found in the plants near maturity seems to be in conformity with this conception.

EFFECT OF FERTILIZER TREATMENT UPON THE COMPOSITION OF THE SOYBEAN

THIRTY-FIVE DAYS AFTER SEEDING

The effects of the fertilizer treatment upon the composition of the soybean plant were small. This study was made at three periods during the growing season and the comparisons drawn for each period separately.

The treatment of magnesic lime and phosphorus increased the ash, calcium, and magnesium contents of the plants grown on Kewanee loam (Table 4, A). This treatment decreased the nitrogen content of the plants grown on Coloma sand and Miami loam (Table 5, A). The phosphorus treatment on Brookston clay loam[5] (Table 2, A) increased the ash and magnesium contents of the plants and decreased the nitrogen content of these plants. The effects attributed to the addition of phosphorus to this treatment were increases in the ash and calcium contents of the plants grown on Coloma sand (Table 3, A). No appreciable decreases in the plant content of the respective elements were produced by the addition of the phosphorus to the fertilizer treatment.

Magnesic lime, phosphorus, and sulfur on Coloma sand (Table 3, A) increased the ash and magnesium contents of the plants, while on Kewanee loam (Table 4, A) it increased the ash content. This treatment decreased the calcium and nitrogen contents of the plants on Coloma sand and the nitrogen content of the plants on Miami loam (Table 5, A) On Brookston clay loam (Table 2, A), where the treatment consisted of phosphorus and sulfur and no lime, the magnesium content of the plants was increased and the nitrogen content decreased. The introduction of sulfur into the fertilizer treatment caused a decreased nitrogen content of the plants on Coloma sand (Table 3, A).

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[5] No lime was applied on Brookston clay loam.

The fertilizer treatment consisting of magnesic lime, phosphorus, sulfur, and potassium increased the ash content of the plants grown on Kewanee loam (Table 4, A), the ash and potassium contents of the plants grown on Coloma sand (Table 3, A), and the magnesium content of the plants grown on Brookston clay loam (Table 2, A). The nitrogen content of the plants on all four soils (Brookston, Coloma, Kewanee, and Miami) and the calcium content of the plants grown on Coloma sand receiving this treatment were decreased. The decrease in the calcium content of the plants grown on Miami loam (Table 5, A), the nitrogen content of the plants grown on Kewanee loam (Table 4, A), and the calcium, magnesium, and nitrogen contents of the plants grown on Coloma sand are also attributed to the potassium in the fertilizer treatment of these plats.

The complete fertilizer treatment increased the ash and magnesium contents of the plants grown on Brookston clay loam (Table 2, A), the ash and potassium contents of the plants grown on Coloma sand (Table 3, A), and the ash content of the plants grown on Kewanee loam (Table 4, A). The only appreciable decreasing effect from the complete fertilizer occurred in the nitrogen content of the plants grown on Brookston clay loam (Table 2, A), Kewanee loam and Miami loam (Table 5, A), and in the calcium content of the plants grown on Coloma sand. Effects attributed to the nitrogen in this fertilizer treatment were an increased nitrogen content of the plants grown on Coloma sand and Miami loam and an increased ash content of the plants grown on Brookston clay loam, Kewanee loam, and Miami loam.

The foregoing notations of the decreased and increased effects of the fertilizer treatment upon the composition of the plants 35 days after seeding represent only a part of the possibilities. Many cases did not show any effects, and others were too small for consideration. Each fertilizer treatment caused both increases and decreases in some one or more elements, but the number of increases was greater than the number of decreases. Each fertilizer treatment decreased the nitrogen content of the plants, except the treatment of magnesic lime, phosphorus, and sulfur on Kewanee loam. The ash content was increased by each treatment on one or more of the soils. Both calcic and magnesic lime exerted a depressing effect upon the calcium content of the young plants. The phosphorus, sulfur, and potassium contents were not affected by the fertilizer treatments. The composition of the young plants (35 days after seeding) was affected by the fertilizer treatment, but the changes for the most part were comparatively small.

SEVENTY-THREE DAYS AFTER SEEDING

The calcic lime treatment on Coloma sand (Table 3, B) increased the ash content of the plants. The increase in the nitrogen content of the plants on Fox sandy loam from 2.72% for the check plat to 3.74% for the calcic lime application was a very appreciable one. The ash content of the plants grown on Fox sandy loam was decreased by the application of calcic lime.

The magnesium content of the plants grown on Coloma sand (Table 3, B) and the ash and nitrogen contents of the plants grown on Kewanee loam (Table 4, B) were increased by the magnesic lime treatment in comparison with both calcic lime and check treatments. The only decreasing effect of the magnesic lime was upon the nitrogen content of the plants, on Coloma sand. The ash content of the plants on Coloma sand was the only constituent that was higher in the plants receiving calcic lime than in those receiving magnesic lime.

The treatment of magnesic lime and phosphorus increased the calcium and magnesium contents of the soybean plants grown on Coloma sand (Table 3, B). The ash and nitrogen contents of these plants and the plants grown on Brookston clay loam were decreased by this treatment. A comparison of the composition of the plants receiving applications of magnesic lime alone and with phosphorus reveals an increase in the calcium content and a decrease in the ash content of the plants grown on Coloma sand and a decrease in the ash content of the plants on Kewanee loam (Table 4, B) due to the addition of the phosphorus in the treatment. The nitrogen content was increased from 2.72% in the plants on the check plat to 4.34% in the plants on the plat receiving calcic lime and rock phosphate on Fox sandy loam. This, with a similar increase from an application of lime and nitrogen (Table 6, sample 658a), was the largest increase in nitrogen obtained from fertilization. A decrease also occurred in the ash content of the plants on the plat receiving the lime and phosphorus. The ash and nitrogen contents of these plants were higher than the ash and nitrogen contents of the plants receiving an application of calcic lime alone on Fox sandy loam.

The fertilizer treatment of magnesic lime, phosphorus, and sulfur increased the calcium and magnesium contents and decreased the ash and nitrogen contents of the plants grown on Coloma sand (Table 3, B). The phosphorus and sulfur treatment on Brookston clay loam resulted in no increases but did result in a nitrogen content of 2.36% in comparison to 3.46% nitrogen in the plants receiving no fertilizer on Brookston clay loam. A treatment of calcic lime, phosphorus, and sulfur[6] on Fox sandy loam (Table 6) increased the calcium and nitrogen and decreased the ash contents of the soybean plants.

The magnesic lime, phosphorus, sulfur, and potassium treatment increased the ash content of the plants grown on Miami loam (Table 5, B). This treatment also decreased the ash and nitrogen contents of the plants grown on Coloma sand (Table 3, B) and the nitrogen content of the plants grown on Miami loam. On Brookston clay loam, this treatment, which did not include lime, decreased the ash and nitrogen contents of the plants, but did not cause any increases. The calcium and nitrogen contents of the soybean plants were increased by the treatment of calcic lime, phosphorus, sulfur, and potassium on Fox sandy loam (Table 6, sample 656). The ash content suffered a marked decrease. It was 8.56% in these plants and 10.57% in the plants on the check plat. Only one increase resulted from addition of potassium to the fertilizer application. This was the nitrogen content of the plants on Brookston clay loam (Table 2, B). Decreases occurred in the ash, calcium, and magnesium contents of the plants on Coloma sand (Table 3, B).

The application of complete fertilizer produced increases in the mineral constituents of the plant only on Kewanee loam (Table 4, B) and Fox sandy loam (Table 6). The nitrogen content of the plants on Kewanee loam was increased. The treatment of calcic lime, phosphorus, sulfur, potassium, and nitrogen on Fox sandy loam increased the calcium and nitrogen and decreased the ash content of the plants. The nitrogen content of the plants on Miami loam (Table 5, B) and the ash, calcium, and nitrogen contents of the plants on Coloma sand (Table 3, B) were lowered by the application of the complete fertilizer. No increases occurred in the plants on Brookston clay loam (Table 2, B), but decreases did occur in the ash and nitrogen contents. The addition of nitrogen in the fertilizer application was accompanied by an increase in the nitrogen content of the plants on Kewanee loam (Table 4, B) and a decrease in the ash content of the plants on Miami loam (Table 5, B) and on Fox sandy loam (Table 6).

[6] The phosphorus and sulfur were supplied in the superphosphate.

TABLE 6.—*Analysis based on dry weight of soybeans on Fox sandy loam, Cassopolis, 75 days after seeding (Aug. 14).*

Sample No.	Treatment*	Ash %	Ca %	Mg %	N %	S %	P %	K %
651	none	10.57	1.894	0.665	2.725	0.347	0.377	0.511
652	Lime	7.72	2.078	0.822	3.740	0.244	0.296	0.487
652a	Lime K	8.35	2.025	0.783	4.246	0.271	0.281	0.521
653a	Lime S R-P	8.80	2.302	0.767	3.940	0.266	0.405	0.436
654a	Lime R-P	8.68	2.288	0.881	4.342	0.287	0.398	0.468
655	Lime S-P	8.63	2.292	0.832	4.112	0.273	0.405	0.484
656	Lime K S-P	8.56	2.315	0.680	3.867	0.273	0.362	0.688
657	Lime K S-P N	7.29	2.152	0.729	3.962	0.234	0.299	0.466
658a	Lime N	8.30	1.999	0.967	4.394	0.252	0.346	0.497
658c	Lime K N	7.93	2.058	0.624	3.609	0.246	0.284	0.564
659a	Lime S-P N	7.72	2.121	0.794	3.948	0.237	0.328	0.464

*Lime = 6,300 pounds of calcic lime per acre.
K = 100 pounds of muriate of potash per acre.
R-P = 1,000 pounds of rock phosphate per acre.
S-P = 200 pounds of superphosphate per acre.
N = 100 pounds of nitrate of soda per acre.
S = Gypsum equivalent to that in 200 pounds of superphosphate per acre.

The effects of the fertilizer treatments on the plants 73 days after seeding were quite irregular, as was also true in the case of the younger plants. Though definite conclusions are not possible, there are some marked evidences of definite effects. The lime applications did not have the same depressing effect upon the calcium content of these plants as was noted in the younger plants. Also, the lime applications did not show any effects upon the composition of plants on Miami loam. The phosphorus, sulfur, and potassium contents of the plants were not affected by the fertilizer treatments, which was also true in the younger plants. Each fertilizer treatment on Fox sandy loam caused an increase in nitrogen content of the plants. This increase is notable because the only other increases were for the magnesic lime and complete fertilizer treatments on Kewanee loam.

ONE HUNDRED TEN DAYS AFTER SEEDING

The only appreciable effect of calcic lime alone upon the composition of soybean plants approaching maturity was an increased nitrogen content of the plants on Miami loam (Table 5, C). The nitrogen content of the plants on Miami loam and the magnesium and nitrogen contents of the plants on Coloma sand were the only constituents of the plants that were increased by the magnesic lime treatment. The depressing effects of the magnesic lime were noted in the nitrogen content of the plants on Kewanee loam (Table 4, C) and the calcium content of the plants on Miami loam (Table 5, C) and Coloma sand (Table 3, C). A higher calcium content of the plants on Miami loam and a higher nitrogen content of the plants on Kewanee loam resulted from the treatment of calcic lime than from the treatment of magnesic lime. On the other hand, there was a higher content of magnesium and nitrogen in the plants on Coloma sand and a higher content of calcium in the plants on Kewanee loam from the application of magnesic lime than from the application of calcic lime.

There was no appreciable increase from the application of phosphorus, either with or without lime. Several depressing effects occurred as follows: The nitrogen content of the plants on Miami loam, the ash and nitrogen contents of the plants on Kewanee loam (Table 4, C), the calcium content of the plants on Coloma sand (Table 3, C), and the ash and nitrogen contents of the plants on Brookston clay loam (Table 2, C).

The phosphorus and sulfur treatments on the Brookston clay loam caused increases in the ash and calcium and a decrease in the nitrogen content of the plants. The treatment of magnesic lime, phosphorus, and sulfur on the other soil types caused no increases in the mineral content of the plants. Decreasing effects, however, occurred in the nitrogen content of the plants grown on Coloma sand (Table 3, C) and Kewanee loam (Table 4, C), and in the ash and calcium contents of the plants on Coloma sand. An increased ash content of the plants on Kewanee loam and nitrogen content on Miami loam and a decreased ash content in the plants on Coloma sand and Miami loam were attributed to the addition of sulfur to this fertilizer treatment.

The treatment consisting of magnesic lime, phosphorus, sulfur, and potassium increased the ash content of the plants on Coloma sand (Table 3, C) and the nitrogen content of the plants on Miami loam (Table 5, C). This treatment also decreased the calcium and nitrogen contents of the plants on Coloma sand. The effects attributed to the addition of potassium to the fertilizer treatment were an increased ash content of the plants on Coloma sand (Table 3, C) and Miami loam (Table 5, C) and an increased nitrogen content of the plants on Brookston clay loam (Table 2, C), Kewanee loam (Table 4, C), and Miami loam.

The complete fertilizer increased the nitrogen content of the plants on Miami loam (Table 5, C). The treatment also decreased the ash content of the plants on Brookston clay loam (Table 2, C), Coloma sand (Table 3, C), and Kewanee loam (Table 4, C); the nitrogen content on Brookston clay loam and Coloma sand; and the calcium content on Coloma sand. No increases resulted from the addition of the nitrogen to this fertilizer application. However, it did cause a decreased ash and nitrogen content of the plants on Brookston clay loam and on Coloma sand.

The foregoing data and notations of the effects of the treatments upon the composition of the plants are, for the most part, quite irregular. However, there are some regularities. The phosphorus, sulfur, and potassium contents were not appreciably changed by the treatments. There were few increased ash contents, but many decreased ash contents. These resulted more from the treatment carrying two or more elements. A decrease in the mineral elements resulting in an increased growth certainly resulted in an increased content of other constituents, such as carbohydrates, etc. Though no yields were obtained, increased growth did result from all treatments on each soil, except possibly some of the lime treatments. It is the opinion of the writer that these soils do not suffer from a deficiency of phosphorus in comparison to other elements, though one or two of the soils may be low in total phosphorus content.

A shortage in phosphorus available to plants, when the other elements are available in sufficient amounts for normal growth, constitutes a true and detrimental shortage from which the composition of the plant will doubtless suffer. This condition surely has not existed in the soils under experimentation Doubtless, phosphorus was not abundantly available in Coloma sand and Kewanee loam, but it was also as probable that nitrogen, potassium, and other factors were not up to optimum for production, for there was a visable response to fertilization. The effects upon the growth of the plants was less, the growth on all treatments was also greater, and the effect upon the composition of the plants was less on Miami loam than on either Kewanee loam or Coloma sand. A shortage of an element necessitates, to a certain extent, an unbalanced proportion of the elements available to the plants. Effects from soil treatments upon the composition of the plant certainly can be expected where there is a deficiency of some one or two of the added elements, but where there is a condition approximating a balance any moderate fertilizer treatment does not give regular and appreciable effects upon the composition of the plant. A lack of control of the many contributing factors accounts in part for the irregularity in the results which have been reported upon the subject.

EFFECT OF SOIL TYPE UPON THE COMPOSITION OF THE SOYBEAN

A study of the effect of the soil type upon the composition of the soybean plant was made upon the untreated soils used in these experiments at the three periods during the growth of the plants. The comparisons are drawn for each period separately.

THIRTY-FIVE DAYS AFTER SEEDING

The plants grown on Hillsdale sandy loam and Coloma sand had the highest ash (10.70% and 10.12%) and calcium (2.70% and 2.79%), and the lowest magnesium (0.58% and 0.69%) and nitrogen (4.41% and 4.17%) contents. The calcium content was the lowest in the plants grown on Kewanee loam (2.08%). The soybeans grown on the Brookston clay loam had the highest magnesium content (1.08%), one of the highest nitrogen contents (4.81%), and one of the lowest calcium (2.16%) and ash (9.72%) contents. The Kewanee loam produced plants with the highest (5.06%) and the Miami loam with the second highest (4.97%) nitrogen content. The phosphorus, sulfur, and potassium contents did not vary to any great extent on the soil types used in this experiment.

A general correlation exists between the ash content and the size of the young plants. Those grown on Coloma sand, Kewanee loam, and Hillsdale sandy loam were smaller and had a higher ash content than those grown on Brookston clay loam and Miami loam, which were the largest in size For a finer comparison, this correlation will not hold true, because the plants on Coloma sand and Kewanee loam were the smallest in size and the highest ash content occurred in the plants on Hillsdale sandy loam, which ranked third in size, and second highest in the plants on Coloma sand. An apparent correlation exists between the size of the plant and the magnesium content in that those grown on Brookston clay loam and Miami loam were larger and had a higher magnesium content than those on the other three soils.

SEVENTY-THREE DAYS AFTER SEEDING

Appreciable differences occurred in the ash content of the plants grown on Coloma sand, (11.36%), Brookston clay loam (10.61%), and Fox sandy loam (10.57%). The lowest ash content was in the plants grown on Miami loam (8.58%). Less variation occurred in the calcium content of soybeans 73 days after seeding (Table 7, B) than in the plants 35 days after seeding (Table 7, A). The calcium content was a little higher in the plants grown on Hillsdale sandy loam (2.05%) and was lower in the plants grown on Coloma sand (1.76%) and Brookston clay loam (1.79%) than in the plants grown on the other soils. The Brookston clay loam plants had the highest magnesium content (1.08%) and the plants grown on Hillsdale sandy loam had the second highest magnesium content (0.84%). Very little difference existed between the magnesium contents of the plants grown on the other three soils of which the Coloma sand and Kewanee loam plants were the lowest (0.64%).

TABLE 7.—*Analysis based on dry weight of unfertilized soybean plants.*

Sample No.	Soil type	Ash %	Ca %	Mg %	N %	S %	P %	K %
A—35 days after seeding (July 13)								
011	Hillsdale	10.70	2.702	0.586	4.414	0.232	0.234	0.695
111	Brookston	9.72	2.162	1.083	4.815	0.289	0.469	0.635
211	Coloma	10.12	2.799	0.694	4.173	0.318	0.411	0.504
311	Kewanee	9.87	2.081	0.663	5.063	0.275	0.345	0.812
511	Miami	9.46	2.370	0.832	4.977	0.258	0.312	0.663
B—73 days after seeding (Aug. 19)								
051	Hillsdale	9.23	2.050	0.846	3.833	0.283	0.287	0.722
151	Brookston	10.61	1.792	1.086	3.463	0.291	0.374	0.627
251	Coloma	11.36	1.760	0.644	2.163	0.321	0.403	0.729
351	Kewanee	9.41	1.813	0.643	3.556	0.236	0.383	0.623
551	Miami	8.58	1.834	0.773	4.023	0.260	0.242	0.774
651	Fox	10.57	1.894	0.665	2.725	0.347	0.377	0.511
C—110 days after seeding (Sept. 26)								
081	Hillsdale	8.13	1.865	0.719	3.167	0.249	0.329	0.576
181	Brookston	8.56	1.681	0.795	2.291	0.326	0.390	0.713
281	Coloma	8.37	2.115	0.607	2.441	0.286	0.462	0.591
381	Kewanee	6.92	1.294	0.536	3.528	0.277	0.423	0.738
581	Miami	6.29	1.291	0.637	3.277	0.229	0.280	0.532

The nitrogen content of the plants was greatest on Miami loam (4.02%), Hillsdale sandy loam (3.83%), Kewanee loam (3.55%), and Brookston clay loam (3.46%), and was lowest on Coloma sand (2.16%) and Fox sandy loam (2.72%). The difference in the sulfur contents of the plants grown on Kewanee loam (0.23%), the lowest, and on Fox sandy loam (0.34%) was not large. Variations in the phosphorus content of the plants on the soil types used in this experiment were not appreciable. The highest phosphorus content was found in plants on Coloma sand (0.40%), Kewanee loam (0.38%), Brookston clay loam (0.37%), and Fox sandy loam (0.37%). Miami loam and Hillsdale sandy loam plants were the lowest in phosphorus content (0.24% and 0.28%).

The effect of soil type upon the potassium content of the soybean plants was not pronounced. Fox sandy loam plants were the lowest and Miami loam plants were the highest in their content of potassium (0.51% and 0.77%). Practically no difference existed between the potassium content of the plants grown on Coloma sand and those grown on Hillsdale sandy loam (0.72%) and between the plants grown on Brookston clay loam and Kewanee loam (0.62%).

The larger, more thrifty plants, which were those grown on Miami loam and Brookston clay loam, had higher nitrogen and magnesium contents and lower phosphorus and ash contents than the smallest plants grown on Coloma sand. These data lend themselves less to correlations to the size of the plant than did the data for the younger plants.

ONE HUNDRED TEN DAYS AFTER SEEDING

The influence of the soil type upon the composition of the soybean plants at the stage of growth for hay is shown in the data in Table 7, C. The total ash content was the highest in the plants grown on Brookston clay loam (8.56%), Coloma sand (8.37%), and Hillsdale sandy loam (8.13%), and was lowest in the plants grown on Miami loam (6.29%). The magnesium (0.79%) and sulfur (0.32%) contents were the highest in the plants grown on Brookston clay loam, and the calcium (2.11%) and phosphorus (0.46%) contents in the plants on Coloma sand. The Brookston clay loam and Kewanee loam plants contained the highest amount of potassium (0.71% and 0.73%), and the Miami loam plants the lowest (0.53%). Nitrogen was highest in the plants grown on Kewanee loam (3.52%), Hillsdale sandy loam (3.16%), and Miami loam (3.27%), and lowest in the plants grown on Brookston clay loam (2.29%) and Coloma sand (2.44%). Miami loam produced the plants containing the lowest amount of ash (6.29%), calcium (1.29%), sulfur (0.22%), phosphorus (0.28%, and potassium (0.53%), and one of the highest percentages of nitrogen (3.27%).

The influence of soil type upon the composition of the plant is shown in the data given in Table 7. To draw definite correlations between the growth of the plants and the content of an element is difficult because of the irregularities, but there some general correlations are apparent. Plants grown on Miami loam had the lowest content of ash, sulfur, calcium, phosphorus, and potassium, and were among the largest, being exceeded in size only by those grown on Brookston clay loam. The magnesium content of the plants at each period of growth was associated with the larger growth of plants. The calcium content tended to a limited extent to be inversely proportional to that of the magnesium. The calcium and phosphorus contents of these plants were not low to the extent of detrimental effects in the nutrition of livestock consuming them as hay. These soils are therefore not deficient in available phosphorus to the extent of an unbalanced proportion to the other elements, which in all probability, is the condition existing in those localities suffering from the deficiency of lime and phosphorus in the hay and pasture grass produced.

EFFECT OF FERTILIZER TREATMENT UPON THE COMPOSITION OF THE CELL SAP

That the concentration and phosphorus content of the sap of several crops is affected by fertilizer treatments and soil type, has been shown by McCool.[7] In this paper are presented the results of similar studies of the effect of additions of phosphorus and potassium and also the effect of the soil type upon the phosphorus, potassium, and calcium contents of the cell sap of the soybean plant. These studies were confined to greenhouse-grown plants, except for a few samples from field plats on Miami loam.

GREENHOUSE STUDIES

The phosphorus content of the cell sap of the soybean plants 16 days after seeding was not affected by either light or heavy applications of mono-calcium phosphate and potassium chloride on Coloma sand and Plainfield sand. The application of phosphorus and potassium did not cause an increase in the phosphorus content of the cell sap of the plants 33 days after seeding on six of the seven soil types used in this experiment. The effects of the light application were very slight, but relatively large increases resulted from the heavy application of phosphorus and potassium. The phosphorus content of the cell sap of the plants on Fox sandy loam 51 days after seeding (Table 8) was reduced a very small amount by the light application and was not affected by the heavy application. A somewhat similar condition occurred in these plants 33 days after seeding.

TABLE 8.—*Cell sap of soybean plants grown in the greenhouse.*

Soil type	16 days after seeding			33 days after seeding			51 days after seeding		
	Treatment of pots			Treatment of pots			Treatment of pots		
	None	P, 0.2* K, 0.1†	P, 2 K, 1	None	P, 0.2 K, 0.1	P, 2 K, 1	None	P, 0.2 K, 0.1	P, 2 K, 1
	%	%	%	%	%	%	%	%	%
				Phosphorus Content					
Kalamazoo muck	——	——	——	0.006	0.016	0.075	0.025	0.044	0.074
Miami loam.	——	——	——	0.011	0.015	0.036	0.055	0.055	0.092
Nappanee loam.	——	——	——	0.018	0.019	0.033	0.061	0.062	0.073
Kewanee loam. .	——	——	——	0.029	0.031	0.040	0.050	——	——
Coloma sand .	0.029	0.026	0.026	0.033	0.037	0.062	0.057	——	——
Fox sandy loam..	——	——	——	0.024	0.011	0.026	0.056	0.048	0.056
Plainfield sand. .	0.027	0.030	0.028	0.033	——	0.050	0.064	——	——
Berrien sandy loam	——	——	——	——	——	——	0.047	——	——
				Potassium Content					
Kalamazoo muck	——	——	——	0.191	0.192	0.308	0.178	0.188	0.326
Miami loam.. ..	——	——	——	0.089	0.133	0.209	0.212	0.233	0.307
Nappanee loam.	——	——	——	0.212	0.216	0.269	0.240	0.241	0.322
Kewanee loam.	——	——	——	0.171	0.169	0.380	0.246	——	——
Coloma sand ...	0.228	0.210	0.135	0.173	0.281	0.299	0.219	——	——
Fox sandy loam..	——	——	——	0.147	0.169	0.477	0.181	0.213	0.282
Plainfield sand...	0.171	0.169	0.207	0.319	——	0.402	0.209	——	——
Berrien sandy loam	——	——	——	——	——	——	0.263	——	——

*Grams of mono-calcium phosphate per pot.
†Grams of potassium chloride per pot.

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[7] McCOOL, M. M. Relation of soil to plant cell sap. Mich. Agr. Exp. Sta. Quart. Bul., 9: 60–64. 1926.

A marked increase in the phosphorus content of the cell sap of the plants on Kalamazoo muck resulted from both the light and heavy application of phosphorus and potassium. The light application had no effect, but the heavy application increased the phosphorus content of the cell sap of the plants on Miami loam and Nappanee loam.

The potassium content of the cell sap of soybean plants 16 days after seeding showed a tendency for the potassium content to be higher in the plants on Plainfield sand and to be lower in the plants on Coloma sand (Table 8). The effect of the light application of phosphorus and potassium was negligible in the plants on these soils. The study of the potassium content of the cell sap of the plants 33 and 51 days after seeding reveals a general tendency for it to be increased by the treatment However, the effects of the light application were practically nil in the plants 33 days after seeding on Kalamazoo muck, Nappanee loam, Kewanee loam, and Fox sandy loam, and also in plants 51 days after seeding on Kalamazoo muck, Miami loam, Nappanee loam, and Fox sandy loam. Very marked increases were observed in the potassium content of the cell sap of the plants 33 days after seeding from the heavy application of phosphorus and potassium on Kalamazoo muck, Kewanee loam, and Fox sandy loam. The plants on the other soils showed smaller increases from the heavy application in the potassium content of the cell sap of the plants 33 days after seeding The light application had relatively little effect on the potassium content of the cell sap of the plants 51 days after seeding, but the heavy application caused appreciable increases in the potassium content of the cell sap. This effect was most pronounced in the plants grown on Kalamazoo muck.

FIELD STUDIES

The phosphorus content of the cell sap of the soybean plants on the field plats on Miami loam 40 days after seeding was increased by each of the fertilizer treatments, with the exception of the calcic-lime treatment which had no effect (Table 9). The treatment of magnesic lime, phosphorus, and sulfur on plat 5 produced the greatest increase in the phosphorus content of the cell sap of the plants. Seventy-four days after seeding the only indication of an increased effect was also from the treatment on plat 5 and from the complete fertilizer treatment on plat 7 (Table 9). Calcic-lime alone, magnesic-lime alone, magnesic-lime and phosphorus, and magnesic-lime, phosphorus, and sulfur caused decreases in the phosphorus content of the cell sap of the soybean plants 74 days after seeding. The phosphorus content of the cell sap of the plants on the check plat was higher in the older than in the younger plants. The calcic lime alone and the complete fertilizer were the only treatments which produced an increased phosphorus content of the cell sap with the growth of the soybean plant.

TABLE 9.—*Cell sap of soybean plants grown on Miami loam in the field.*

		Phosphorus		Potassium		Calcium	
Date		July 27	Aug. 20	July 27	Aug. 20	July 27	Aug. 20
Days after seeding		49	74	49	74	49	74
Plat No.	Treatment	%	%	%	%	%	%
1	None	0.022	0.038	0.195	0.123	0.342	0.600
2	Ca-lime	0.022	0.034	0.210	0.091	——	0.586
3	Mg-lime	0.036	0.035	0.228	0.251	——	——
4	*Mg P	0.040	0.033	0.104	0.107	——	——
5	*Mg P S	0.044	0.040	0.108	0.179	——	——
6	*Mg P S K	0.040	0.036	0.300	0.177	——	——
7	*Mg P S K N	0.036	0.041	0.210	0.175	——	0.475

*Magnesic lime.

The potassium content of the cell sap of the soybean plants 49 days after seeding was reduced by the application of magnesic lime and phosphorus and magnesic lime, phosphorus, and sulfur. Lime alone did not affect the potassium content of the cell sap of the younger plants to any great extent, but in the older plants the calcic lime alone reduced the potassium content of the cell sap and the magnesic lime increased the potassium content of the cell sap of the soybean plants. The complete fertilizer treatment and the treatment lacking nitrogen increased the potassium content of the cell sap in both the young and the older soybean plants.

EFFECT OF SOIL TYPE UPON THE COMPOSITION OF THE CELL SAP

That the composition of the cell sap is affected by the soil type is shown by the data on the phosphorus, potassium, and calcium contents presented in Tables 8 and 10.

TABLE 10.—*Calcium content of the cell sap of soybean plants grown in the greenhouse.*

Soil type	Calcium content 16 days after seeding %	 33 days after seeding %	 51 days after seeding %
Kalamazoo muck	——	0.255	0.234
Miami loam	——	0.445	0.372
Nappanee loam	——	0.286	0.243
Kewanee loam	——	0.273	0.185
Coloma sand	——	0.228	0.240
Fox sandy loam	——	0.404	0.225
Plainfield sand	0.075	0.341	0.230
Berrien sandy loam	——	——	0.248

The phosphorus content of the cell sap of the soybean plants 33 days after seeding was highest in the plants grown on Kewanee loam.

Coloma sand, Fox sandy loam, and Plainfield sand. Fifty-one days after seeding the phosphorus content of the cell sap of the plants on these soils was again high, and the phosphorus content of the cell sap of the plants on Nappanee loam, Miami loam, and Berrien sandy loam was also high. The phosphorus content of the cell sap of the plants 33 and 51 days after seeding was lowest in the plants on Kalamazoo muck (Table 8).

The potassium content of the cell sap of the plants 33 days after seeding was highest in Plainfield sand, Nappanee loam, and Kalamazoo muck. Fifty-one days after seeding it was highest in the plants on Berrien sandy loam, Nappanee loam, and Kewanee loam. The lowest potassium content of the cell sap of the soybean plants was in the plants on Miami loam, Fox sandy loam, Kewanee loam, and Coloma sand for the period 33 days after seeding, and in the plants on Kalamazoo muck, Fox sandy loam, Plainfield sand, Miami loam, and Coloma sand for the period 51 days after seeding (Table 8).

The calcium content of the cell sap of the soybean plants 33 days after seeding was highest in the plants grown on Miami loam (0.44%) and on Fox sandy loam (0.40%). The lowest figure for this period was in the plants on Coloma sand (0.22%). Fifty-one days after seeding it was lower than it was 33 days after seeding. The highest calcium content of the cell sap of the plants 51 days after seeding was 0.37% in the plants on Miami loam and the lowest was 0.18% in the plants on Kewanee loam. On Fox sandy loam it was much lower at 51 days (Table 10) after seeding than at 33 days after seeding (0.22% and 0.40%).

SUMMARY

Fertilizer tests with soybeans were located on five soil types from which crop samples were taken periodically for laboratory studies. The samples were analyzed for total ash, calcium, magnesium, nitrogen, sulfur, phosphorus, and potassium.

Tests were conducted in the greenhouse to study the effect of soil type and fertilization with phosphorus and potassium upon the phosphorus and potassium contents of the cell sap of the plant.

The total ash content of the soybean plants was lowest 110 days after seeding, and in many cases it was highest 73 days after seeding. In the young plants the high ash content was associated with smaller growth.

The calcium, magnesium, and nitrogen contents of the soybean plant decreased with the age of the plants. There was very little change in the sulfur content during growth or due to the influence of fertilizers or soil type differences. The results of these experiments suggest a tendency for the phosphorus content of the soybean plants to increase during the latter half of the growing period. The potassium content was very irregular, but the variations were small.

The effects of fertilizer treatments upon the composition of the plant were small. Fertilizers were more effective in changing the composition of the soybean plants grown on Coloma sand and least effective on Miami loam.

Plants on Brookston clay loam had the highest magnesium content (1.08%), one of the highest nitrogen (4.81%) and one of the lowest calcium (2.16%) and ash (9.72%) contents 35 days after seeding, among the plants without fertilizer treatment. Plants on Hillsdale sandy loam and on Coloma sand had the highest ash (10.70% and 10.12%) and calcium (2.70% and 2.79%) contents and the lowest magnesium (0.58% and 0.69%) and nitrogen (4.41% and 4.17%) contents of the unfertilized plants 35 days after seeding. The phosphorus content of the unfertilized soybean plants varied from 0.46% in the plants on Brookston clay loam to 0.23% in the plants on Hillsdale sandy loam.

The Brookston clay loam produced plants that had the lowest calcium (1.79%) the highest magnesium (1.08%) and one of the highest ash (10.61%) and nitrogen (3.46%) contents of the unfertilized soybeans 73 days after seeding.

For unfertilized soybeans 110 days after seeding, the plants on Brookston clay loam had the highest ash (8.56%) and magnesium (0.79%) contents, the plants on Coloma sand the highest calcium (2.11%) and phosphorus (0.46%) contents, and the plants on Kewanee loam the highest nitrogen (3.52%) content. Plants on Miami loam contained the lowest ash (6.29%), calcium (1.29%), sulfur (0.22%), phosphorus (0.28%), and potassium (0.53%) contents and one of the highest nitrogen (3.27%) contents of the plants grown on the unfertilized plats 110 days after seeding.

All treatments on Fox sandy loam increased the nitrogen content of the plants.

The phosphorus and potassium contents of the cell sap of soybean plants were increased by applications of phosphorus and potassium. The phosphorus, potassium, and calcium contents of the cell sap were affected by the type of soil upon which the plants grew.

The soil type upon which the soybeans grew was a greater factor in determining the composition of the plants than was the application of moderate amounts of fertilizers.

THE ACCURACY OF COTTON LINT PERCENTAGE FIGURES[1]

J. R. QUINBY and J. C. STEPHENS[2]

INTRODUCTION

Acre yields of lint cotton as determined from plat yields are influenced by certain errors apart from the errors due to soil and seasonal variation. The computation of acre yield of lint cotton involves the use of a figure for lint percentage which is derived by ginning representative samples of the plat production. In view of the differences in lint percentage between varieties (Table 1) and the possible influence of fertilizer, soil, and seasonal conditions on lint percentage, there seems little justification for interpreting results on the basis of seed cotton yields, provided the error introduced into the acre yield of lint cotton by the use of a factor for lint percentage is negligible in comparison to the other errors of field trials.

Errors in ginning, which result in inaccurate lint percentage figures, may be caused by such factors as running the saws at different speeds, allowing the lint flue to choke up, and failure to gin the rolls equally

TABLE 1.—*Lint and clean seed cotton yields and percentages of lint in the 1927 cotton variety test at Chillicothe, Texas, average of four distributed plats.*

Variety	Lint Pounds to the acre	Rank	Clean seed cotton Pounds to the acre	Rank	Percentage of lint
Western Wonder	735	1	1851	6	40.32
Half and Half	726	2	1809	8	40.79
Mebane (4120)	664	3	1873	5	35.68
Cook	631	4	1915	2	33.53
New Boykin	615	5	1822	7	34.28
Wilson's Cleveland Big Boll	605	6	1918	1	31.94
Lankart	604	7	1630	17	37.52
Kasch	602	8	1668	16	36.60
Bank Account	596	9	1784	11	34.12
Mebane (9611)	589	10	1618	19	36.74
Westex	571	11	1903	4	30.48
Lone Star	570	12	1586	20	36.33
Delfos	557	13	1906	3	29.79
Cliett's Superior	546	14	1519	22	36.62
Sunshine	544	15	1786	10	31.09
Mebane (804)	536	16	1741	13	31.18
Lightning Express	520	17	1807	9	29.18
Burnett	519	18	1756	12	29.97
Rowden	512	19	1622	18	32.06
Blue Wagon	508	20	1505	23	34.18
Acala	504	21	1707	14	29.95
Trice	459	22	1697	15	27.37
Snowflake	448	23	1568	21	28.89
Durango	371	24	1299	24	28.80

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[1] Contribution from Department of Agronomy, Texas Agricultural Experiment Station. Technical paper No. 70. Received for publication July 29, 1929.

[2] Superintendent, Substation No. 12, Chillicothe, Texas; and Assistant Agronomist, Office of Forage Crops, U. S. Dept. of Agriculture, respectively.

well. Assuming, however, that the gin functions properly and that weighing and other mechanical operations are reasonably accurate, additional sources of error may be (1) improper method of taking samples and (2) failure to secure the right size or a correct number of samples to give the determinations sufficient reliability.

This experiment was conducted to determine the kind, the size, and the number of samples of seed cotton necessary to obtain sufficiently accurate figures for percentage of lint.

MATERIAL AND METHODS

Three 10-pound samples of seed cotton, one each from the early, medium, and late pickings, were taken from each of 24 varieties in the cotton variety test at Texas Substation No. 12, Chillicothe, to show an error which may result from improper sampling.

Fifty samples each of 10 pounds and 30 pounds were weighed accurately to one-fourth of an ounce from a thoroughly mixed bulk of Mebane cotton and used to determine the size of samples and the number of samples necessary for reliable lint percentage figures when ginning is done in a 20-saw gin. Fifty 200-gram samples were weighed to the nearest gram and used to determine the number of samples required for accurate lint percentage figures when ginning is done in a small 8-saw gin.

A 10-pound sample is the proper size to make a good roll in the 20-saw gin, and 10 pounds is also a convenient figure from which to make calculations. A 30-pound sample is roughly representative of average plat yields of seed cotton on Texas substations, and a 200-gram sample approximates the average seed cotton production of a single plant. The 20-saw gin is the type of experimental gin ordinarily used on Texas substations and is operated at a saw speed of about 400 revolutions a minute. The small 8-saw gin is the type ordinarily used to gin individual stalk selections and is operated at a saw speed of about 350 revolutions a minute. The capacity of the larger gin is about 100 10-pound samples a day, and that of the smaller gin is about 100 200-gram samples a day.

Percentage of lint may be computed as the ratio of lint to raw cotton (lint plus seed plus dirt and waste) or as the ratio of lint to clean seed cotton (lint plus seed). Both methods of computing percentage of lint were used.

Dirt and waste is that part of the total sample which is lost in the process of ginning. This loss consists largely of dirt, motes, and burs, but includes occasional locks and seed, and also the lint that escapes from the lint flue or is not caught by the condenser.

All calculations were carried to the nearest third decimal place.

THE RESULTS

COMPOSITE SAMPLES

The sample must be representative of the entire plat production of seed cotton. An error of considerable magnitude will be introduced into the figure of lint percentage if the sample is not taken from the thoroughly mixed total seed cotton production of the plat (Table 2). This error is evident since in most varieties the medium and late pickings have a higher percentage of lint than the early pickings, and the medium pickings generally have a higher percentage than the late pickings. The maximum differences in the percentage of lint between early and medium, medium and late, and early and late pickings, regardless of which picking is the higher, are shown at the bottom of the table, and also, the means of all differences summed regardless of sign.

TABLE 2.—*Percentage of lint in 10-pound samples from an early, medium, and late picking of each variety in the 1928 cotton variety test at Chillicothe, Texas.*

Variety	Percentage of lint Early picking	 Medium picking	 Late picking
Half and Half	41.38	44.39	44.63
Western Wonder	40.51	43.72	43.44
Cliett's Superior	37.83	40.68	37.36
Mebane	37.82	39.74	36.87
Kasch	36.78	39.64	37.96
Lankart	37.44	38.55	37.56
Lone Star	37.42	37.94	36.42
Blue Wagon	35.93	38.36	35.73
Cook	35.04	37.12	36.24
Bank Account	35.06	36.03	34.22
New Boykin	31.95	36.00	35.42
Mebane (4120)	31 53	35.80	35.73
Mebane (804)	31.13	33.28	34.59
Wilson's Cleveland Big Boll	32.09	33.65	32.97
Sunshine	30.83	32.80	33.59
Durango	29.89	32.91	32.86
Rowden	31.72	31.53	31.37
Acala	28.73	32.91	32.08
Westex	29.21	31.93	32.50
Lightning Express	28.54	30.49	29.73
Snowflake	29.72	30.21	28.73
Delfos	28.60	30.38	29.24
Greer Wichita	29.47	29.35	29.15
Trice	27.52	29.01	31.03
Maximum difference between:			
Early and medium pickings—Mebane (4120)			4.27
Medium and late pickings—Cliett's Superior			3.32
Early and late pickings—Mebane (4120)			4.20
Arithmetical mean of differences between:			
Early and medium pickings			2.12
Medium and late pickings			1.12
Early and late pickings			1.81

If it is not feasible to save the entire plat production until the time of ginning, the correct procedure would be to save a fixed percentage of the seed cotton from each picking and at the end of the season to mix this bulk thoroughly and draw a random sample.

SIZE OF SAMPLES

Ginning of the entire plat production of seed cotton is unnecessary if the ginning of a smaller sample results in an equally accurate figure for lint percentage. The distribution of percentages of lint of the 50 samples of each size, and the means, the standard deviations, the probable error of single determinations, and three times the error of a difference between two single determinations are given in Table 3.

The fact that the standard deviation of 10-pound samples is as low as that of 30-pound samples is assurance that it is unnecessary to gin the entire plat production. The accuracy of the figures for percentage of lint for the three samples of different sizes is in order from greatest accuracy (lowest standard deviation) to least accuracy (highest standard deviation) as follows: 10-pound, 30-pound, and 200-gram. The difference in standard deviation between 10-pound and 30-pound samples is about 0.008% of lint, or equivalent to about 0.08 pound of lint on the basis of an acre yield of 1,000 pounds of seed cotton. The difference in standard deviation between the 10-pound samples and the 200-gram samples is about 0.2% of lint, or equivalent to about 2 pounds of lint to the acre on the same basis.

There is a significant difference between the means of percentages of lint in the samples of different sizes. The mean percentage of lint is highest for the 30-pound samples and lowest for the 200-gram samples. However, the difference between means of the 30-pound and 200-gram samples is only about 1.5% of lint. Assuming a seed cotton yield of 1,000 pounds to the acre, 1.5% would be equivalent to 15 pounds of lint.

An unnecessary error would be introduced into the acre yield of lint cotton if indiscriminate use were made of samples of different sizes. All figures on a given station should be made comparable by the use of samples of one size, but the difference between the figures of the percentages of lint from samples of unequal size is relatively unimportant in broad comparisons such as yields of one station with those of another.

NUMBER OF SAMPLES

The number of samples necessary to be ginned is determined by the accuracy required. As there are effective errors from other sources, there is little reason for refining the ginning methods beyond the point of practicability.

Table 3.—*Frequency distributions and constants for percentages of lint as determined with 50 samples eıch of 200 grams, 10 pounds, and 30 pounds from a well mixed bulk of Mebane cotton.*

Class	Percentage of lint in raw seed cotton			Percentage of lint in clean seed cotton		
	200 grams*	10 pounds	30 pounds	200 grams	10 pounds	30 pounds
31.4–31.5	1					
31.6–31.7						
31.8–31.9						
32.0–32.1	7					
32.2–32.3						
32.4–32.5	16					
32.6–32.7		1				
32.8–32.9				1		
33.0–33.1	21					
33.2–33.3		1	1	1		
33.4–33.5	3	3				
33.6–33.7		7		1		
33.8–33.9		25	4	1	1	
34.0–34.1	2	7	11	5	1	1
34.2–34.3		3	12	6		
34.4–34.5		3	12	5	4	
34.6–34.7			7	14	12	1
34.8–34.9			3	6	20	2
35.0–35.1				4	9	7
35.2–35.3				2	3	8
35.4–35.5				2		17
35.6–35.7				1		6
35.8–35.9				1		8
Mean	32.750±.049	33.850±.028	34.294±.029	34.578±.052	34.794±.025	35.382±.033
Standard deviation	0.516±.035	0.297±.020	0.305±.021	0.545±.037	0.262±.018	0.348±.024
P. E. of single determination	0.348	0.200	0.206	0.368	0.177	0.235
Three times error of difference between two single determinations	1.476	0.849	0.873	1.560	0.750	0.996

*Lint in each sample was weighed to the nearest gram. This weight divided by 200 grams (total sample) always gave a percentage with a whole or 0.5 unit figure which accounts for the grouping in this column.

The probable error in percentage of lint in ginning a single 10-pound sample is 0.200. If three times the probable error of a difference is considered significant, then a difference of 0.849% of lint between two single determinations of 10-pound samples is significant. This difference is equivalent to 8.49 pounds of lint on the basis of a yield of 1,000 pounds of seed cotton to the acre. Probably no one would attach importance to differences in yield as small as 8 or 9 pounds of lint to the acre, and if such differences are considered to be unimportant, a single 10-pound sample is sufficient to be ginned.

In case a 20-saw gin was not available, ginning three 200-gram samples in an 8-saw gin would give an error approximately equal to the error which results from ginning a single 10-pound sample in a 20-saw gin. However, since three times the error of a difference between two single determinations of 200-gram samples ginned in an 8-saw gin is only 1.476% of lint, which is equivalent to about 15 pounds of lint with a seed cotton yield of 1,000 pounds to the acre, there would seldom be justification for increasing the amount of ginning by as much as three times in order to reduce a significant difference 6 or 7 pounds of lint to the acre.

Some importance is attached to a lint percentage figure as a thing in itself, and if it is desired to recognize small differences in percentage of lint, greater accuracy may be obtained by ginning more samples of any of the different sizes.

From what little evidence the literature affords on the magnitude of the error due to the effect of varying seasons and from the numerous reports on plat variability, it seems that one would be amply conservative to estimate the effective error from these sources to be not less than 5 to 7%. Errors as low as 0.2 to 0.4 in percentage of lint which cause errors in lint yield of 0.5 to 1.5%, therefore, are relatively unimportant.

COMPUTING PERCENTAGE OF LINT

As previously mentioned, percentage of lint may be computed in two ways, *viz.*, as the ratio of lint to raw cotton (lint plus seed plus dirt and waste), or as the ratio of lint to clean seed cotton (lint plus seed). Either method gives the same final yield of lint cotton to the acre. For example, if a 10-pound sample which is ginned yields 3.04 pounds of lint, 6.46 pounds of seed, and 0.50 pound of dirt and waste, the percentage of lint by the first method is $\frac{3.04}{10} \times 100$ or 30.4. This figure, multiplied by 1,000 pounds (an assumed acre yield of raw cotton), gives 304 pounds which is the acre yield of lint cotton.

By the second method the percentage of lint is 3.04 divided by 9.50 (lint plus seed) × 100 or 32.00. The percentage of clean seed cotton is 95.00 $\left[\frac{(3.04+6.46)100}{10}\right]$, and this factor multiplied by 1,000 gives 950 pounds of clean seed cotton. This figure multiplied by the percentage of lint (32.00) results in 304 pounds which is the acre yield of lint cotton.

The Texas Station uses the second method on the assumption that it is the more desirable because these figures for percentage of lint are more nearly comparable. This method avoids the effect of actual differences known to exist in the amount of dirt and waste in different lots of seed cotton at the time of harvest.

The discussion of size and number of samples necessary in computing percentage of lint in raw cotton is generally applicable to computing the percentage of lint in clean seed cotton.

SUMMARY

When cotton is ginned in an experimental gin, it is necessary to get a representative sample of the entire plat production of seed cotton or a composite sample of amounts in exact proportion to the yields of each picking if accurate figures for percentage of lint, and consequently for acre yield, are to be obtained.

The two gins which were used, one an 8-saw and the other a 20-saw, ginned random samples from a mixed bulk of Mebane cotton with consistent accuracy, and the effect of errors in ginning upon the acre yield of lint cotton computed from plat yields is unimportant.

One sample is sufficient to give reliable acre yields of lint cotton when the samples are ginned on either gin, although the use of the larger gin gives the more accurate result. If fine distinctions between percentages of lint are desired, more samples may be used.

In view of the accuracy of figures for percentage of lint as derived by the use of an experimental gin, there is little justification for interpreting the results of field trials on the basis of seed cotton yields. Lint cotton yields should be used.

Percentage of lint may be computed in two ways, *viz.*, as the ratio of lint to raw cotton, and as the ratio of lint to clean seed cotton. Either method gives the same final yield of lint cotton to the acre. The second method is the more desirable since it avoids the effect of actual differences in the amount of dirt and waste in the seed cotton as harvested.

RELATION OF BLADE INJURY TO THE YIELDING ABILITY OF CORN PLANTS[1]

George H. Dungan[2]

INTRODUCTION

The purpose of this investigation was to obtain information that will facilitate the estimation of losses to the corn crop caused by hail. Results to date, while not complete enough to permit the shaping of a definite formula for calculating hail losses, do throw some additional light on the problem.

The corn used was a vigorous, uniform, open-pollinated strain of Reid Yellow Dent. The plats were 20 hills long and each row on the plat contained an average of 40 plants. Each treated row was between two untreated rows. The average yield of the plants in the two adjoining untreated rows was considered as the check in determining the degree of iniury caused by the treatment

Different treatments were employed in which a definite percentage of the leaf area was removed from the plants. One method by which this was accomplished involved the clipping of a certain number of blades from each plant in the row. Hand shears were used and the amputation was made at the junction of the sheath and blade. When it was desired to remove one average blade from each plant in a certain row, the lowest green blade was clipped from the first plant, the second blade from the second plant, the third blade from the third plant, and so on to 12, which was the average number of blades on the plants. The process was repeated beginning with the thirteenth plant, from which the lowest blade was removed. Since there were 40 plants in each row and each plant had 12 leaves, it follows that there were approximately 3 blades taken from each level on the stalks in each row. While the plants that had the middle blades removed lost a somewhat greater leaf area than those with the blades clipped from near the base or top of the plants, yet it is believed legitimate to consider that an average blade had been removed from all the plants in the row. Therefore, by dividing the number of blades removed by the total number of blades originally on the plants, the percentage of the leaf area removed was obtained. Thus, each blade removed per plant represented a reduction in leaf area of approximately 8%.

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[1] Contribution from Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication August 2, 1929.

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Two blades per plant were removed by cutting off the first and sixth from the first plant, the second and seventh from the second plant, the third and eighth from the third plant, and so on. Another row was treated by removing three blades per plant, another four, and so on to the last row, which had all the blades removed. These treatments were administered at different stages in the plant's development. The appearance of plants with three, eight, and all blades removed is shown in Figs. 1, A, B, and C.

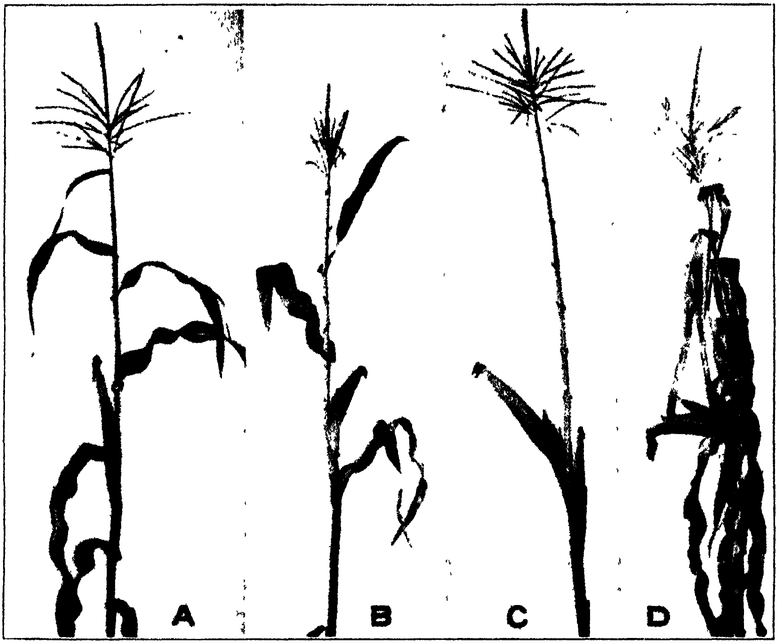

FIG. 1.—Corn plants with blades removed or mutilated. A, three blades removed; B, eight blades removed; C, all blades removed; D, mid-rib of all blades broken approximately 3 inches from the plant.

Other methods of mutilation were (1) clipping off the tip half of the blades (Fig. 2, A); (2) the removal of one side of the blade by splitting it longitudinally alongside the mid-rib (Fig. 2, B); (3) cutting the blade from each side to the mid-rib in 4-inch segments and removing alternate 4-inch pieces (Fig. 2, C); (4) breaking the mid-rib of all the blades about 3 inches from the stalk (Fig. 1, D); and (5) cutting the blades crosswise to the mid-rib on both sides about 3 inches from the plant (Fig. 2, D). An attempt was made to prevent excessive loss of water through wounds by removing the blades and parts of blades during cloudy weather or late in the afternoon.

RESULTS

In accordance with the results of former experiments[3] the greatest reduction in yield occurred when the leaf area was reduced early in the development of the plant. A summary of the data is presented in graphic form in Fig. 3.

It may be noted that the first treatments were administered on August 1. At that time, all the plants were in tassel and 10% of the shoots were in silk. The maximum blade area removed at this stage was 22%, which resulted in a 21% reduction of yield. This was the greatest lowering of yield as a result of the removal of a like percentage of leaf area.

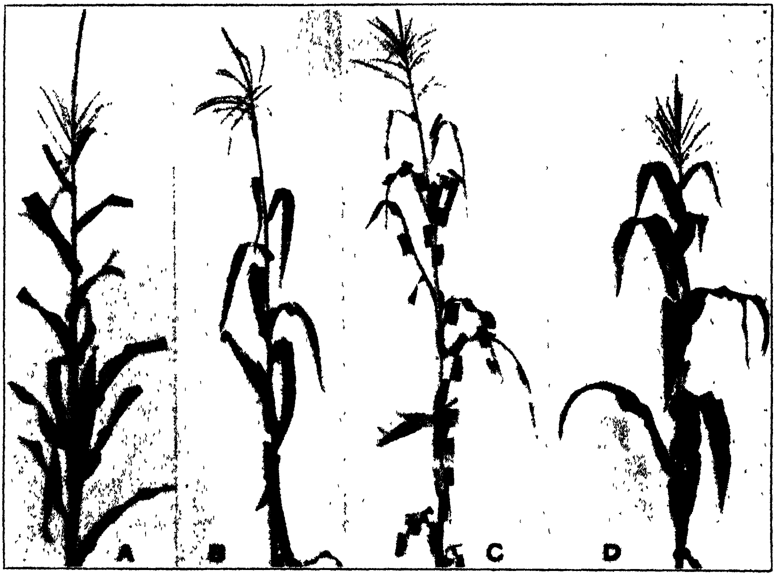

FIG. 2.—Corn plants with portions of blades removed or mutilated. A, outer or tip-half of all blades clipped off; B, one side of the blade removed by splitting it longitudinally alongside the mid-rib; C, 4-inch segments of blade removed on alternate sides of mid-rib; D, all blades cut on both sides to the mid-rib 2 inches from the plant.

There is a slight tendency for the yield to be reduced with the removal of one average blade per plant. It was not until after a little more than 30% of the blades were cut away, however, that there was a distinct lowering of the yield. This obtains for the treatments applied (1) on August 11 when 56% of the plants had silks slightly brown; (2) on August 18 when 76% of the plants had brown silks; and (3) on August 28 when the grain was in the milk stage. The grain on September 15 was in the early dent stage. Development at this stage had progressed so far that the removal of blades produced no harmful influence. In fact, the data suggest that the removal of blades at this time may actually increase the yield of grain. The irregular character of the yields obtained is believed to be due to the heterogeneity of the soil.

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[3] DUNGAN, GEORGE H. Effect of hail injury on the development of the corn plant. Jour. Amer. Soc. Agron., 20:51–54. 1928.

HUME, A. N., and FRANZKE, CLIFFORD. The effect of certain injuries to leaves of corn plants upon weights of grain produced. Jour. Amer. Soc. Agron., 21:1156–1164. 1929.

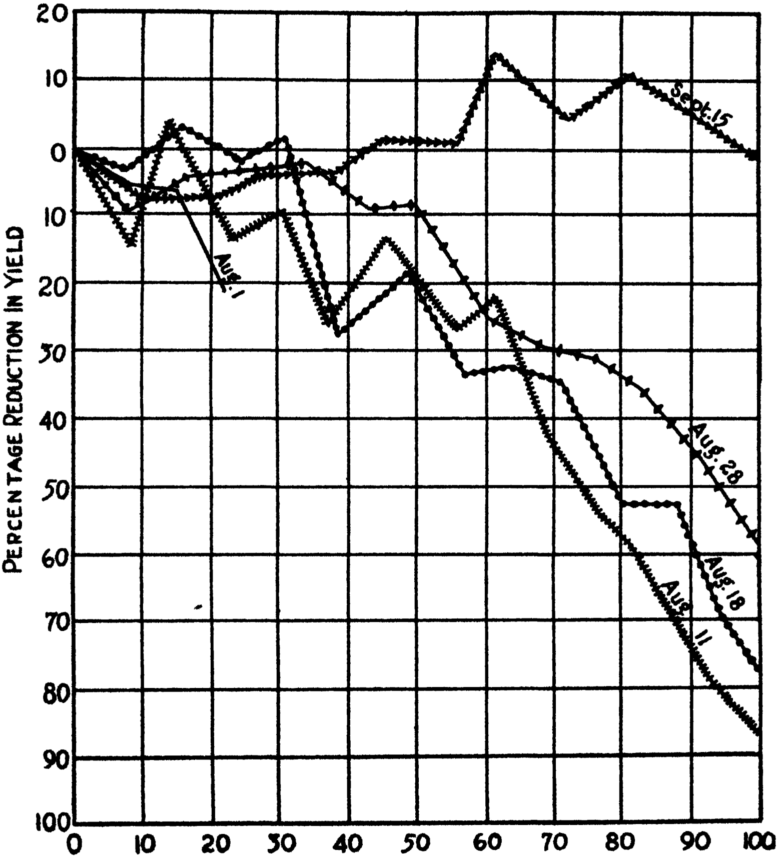

Fig. 3.

Not only was the total yield of grain decreased by the removal of blades, but the quality of the grain was lowered, as well. From data not presented in this paper, it was found that the test weight per bushel of the shelled corn was greatly influenced by the percentage of leaf area removed and the stage of plant development at the time the treatment was administered. The test weight of the corn from treated rows ranged from 55.4 pounds on plants with two blades removed August 1 to 41.8 pounds on plants with all blades removed August 18. As in the earlier experiments, the quality of the grain produced on plants treated before the silks had emerged was not so seriously lowered as in the case of plants treated just after the silks were brown. Early treated plants seemingly were able to adjust the size of the ears to their reduced leaf area and develop grain of approximately normal quality. Reduction of leaf area late in the development of the plant had only a slight lowering effect on the test weight.

Another phase of this investigation was to test the relative value to the plant of different parts of the blades. An attempt was made to remove one-half of the leaf area in four different ways as already described. The results in the form of percentage reduction in grain yield caused by these treatments are presented in Table 1.

TABLE 1.—*Comparative efficiency of various parts of corn blades as measured by the reduction in yield of grain when one-half of the blade area was removed in four different ways.*

Degree of ear development when plants were treated	Percentage reduction in yield of grain with			
	Tip-half of each blade removed	Alternate sections of side of blades removed	One side of all blades removed	One-half of blades removed (six average blades per plant)
76% silks brown....	43.49±4.95	41.66±5.66	29.66±5.38	22.46±5.02
Milk	38.96±4.05	33.54±4.16	28.96±4.21	7.47±4.66
Early dent.	5.59±8.46	————	0.63±9.07	—0.36±9.97

The probable error used in the statistical treatment of the data was calculated in % on the 18 check rows. This value was taken to represent the variation on each of the treated rows. Since the two adjacent checks were added together to get an average value to compare with each treatment, the probable error of the average of two results was used for each of these check means. This method of applying the probable error is based on the assumption that the treatments, if replicated as often as the checks, would show the same variation. While such an assumption may not be altogether justified, it is felt that the error thus made is not serious. In this paper odds of 30:1 or better $\left(\frac{\text{Difference}}{\text{P. E. Diff.}} = 3.2\right)$ are taken to indicate a significant difference.

The basal half of the blades produced a lower yield of grain than any other half of the blades left attached to the plants. The outer or tip-half of the blades was more important from the standpoint of grain production than any other equal portion of the blade studied in these tests. The removal of alternate sections of the blades was much more injurious than the elimination of one side of the blade longitudinally from the mid-rib. In this comparison of depriving the plant of one-half its blade area by different ways, the least reduction in yield occurred where the six entire blades were removed.

The data indicate that when 76% of the plants had brown silks the removal of half the leaf surface in all four ways represented in this experiment produced a significant decrease in yield. Altho the reduction in yield was less when the treatments were applied at the time the grain was in the milk stage, the results show significant decreases for all treatments except for that in which one-half the number of blades was removed.

Of all these treatments, probably the one that most nearly produces an injury similar to natural hail is the removal of 4-inch sections of the blades from alternate sides of the mid-rib.

One of the characteristic types of injury caused by hail is cutting or shredding the blades In an attempt to simulate this injury in a mild degree, the blades were cut to the mid-rib on both sides about 3 inches from the plant, as illustrated in Fig. 2, D. The mid-rib was not severed, though in a few cases the mid-rib later broke at the point where the cut was made in the blade. This injury was so slight as to produce no visual symptoms of plant impairment. As a companion treatment, the mid-ribs were broken about 3 inches from the plant, leaving the blade attached by the sides only, as shown in Fig. 1, D. The percentage reduction in yield of grain resulting from these treatments is presented in Table 2.

TABLE 2.—*Percentage reduction in yield of grain resulting from slight blade injuries to corn plants in different stages of development.*

Degree of ear development when plants were treated	Percentage reduction in yield of grain when	
	Mid-rib was broken	Both sides of blade were cut to mid-rib
10% in silk	23.34±4.91	20.41±4.66
76% silks brown	11.19±5.10	3.87±5.24
Milk	1.43±4.94	6.83±4.48
Early dent	11.65±8.55	—2.57±9.13

Even so slight an injury as slitting the blade to the mid-rib in the early stages of silking resulted in a little over 20% reduction in yield. Breaking the mid-rib was somewhat more harmful than slitting the blades on both sides. The degree of injury caused by these treatments was also very markedly influenced by the stage of the plant's development at the time the injury was inflicted. Only those treatments applied when 10% of the plants were in silk produced significant decreases in yield.

SUMMARY

Definite percentages of the leaf area of corn plants were removed at different stages in the plant's development by the use of hand shears. This was done by taking off whole blades and by cutting out portions of the blades.

The results show that the injury occasioned by blade removal was much more severe when the treatment was applied during the early silk stage than when administered later, and that the reduction in yield became progressively less with each advance in the development of the plant.

The quality of the grain was influenced markedly by loss of blades. Plants having blades removed during the early silk stage were capable of adjusting the size of the ear to the reduced photosynthetic area and they produced grain of almost normal quality. The corn having the lightest test weight was produced by plants treated when 76% of the plants had brown silks.

Cutting off the outer or tip half of each blade was slightly more injurious than cutting out alternate 4-inch sections on each side of the mid-rib and both of these treatments were much more detrimental to yield than the loss of one side of all the blades or the removal of half the number of blades.

Breaking the mid-rib of each leaf was somewhat more harmful than slitting the blade to the mid-rib on each side. These treatments applied during the early silk stage resulted in a little over 20% reduction in grain yield.

THE INACCURACY OF THE QUINHYDRONE ELECTRODE IN MANY KENTUCKY SOILS[1]

P. E. Karraker[2]

A number of investigations have been reported comparing the quinhydrone electrode method with the hydrogen electrode method and with colorimetric methods for determining the hydrogen-ion concentration of soils. Snyder (9)[3] has reviewed these in a recent publication. The general conclusion is that good agreement is to be expected between the quinhydrone electrode method and the other methods with nearly all soils.

There have been relatively few reports of disagreement between the quinhydrone and the other methods. Olsen and Linderstrom-Lang (5) reported a few soils from a large number studied with which the quinhydrone electrode gave higher pH values than the hydrogen electrode, the maximum difference found being 0.8 pH. Brioux and Pien (2) reported most soil suspensions to read higher with the quinhydrone than with the hydrogen electrode. Snyder (9) reported a communication from Pierre to the effect that the quinhydrone electrode gave higher pH values than the hydrogen electrode or colorimetric method with a number of soils. Good agreement was reported by Brioux and Pien and also by Pierre when filtrates were used. McGeorge (4) has recently reported much higher pH values with the quinhydrone electrode than with the hydrogen electrode in the case of manganiferous Hawaiian soils.

On account of the good agreement generally reported between the quinhydrone electrode method and the other methods for determining hydrogen-ion concentration of soils and due to its ease and speed of determination, this method has come into wide use for determining the hydrogen-ion concentration of soils.

In December, 1927, the writer attempted to use the quinhydrone electrode method in determining the hydrogen-ion concentration of a number of surface soils from the western sub-experiment station at Princeton, Kentucky. The quinhydrone electrode method gave results somewhat more than 1.0 pH higher than the hydrogen electrode method. It was not possible to investigate the lack of agreement of the two methods at that time, but since the soils were average Kentucky surface soils and presumably not widely different from soils elsewhere where the quinhydrone electrode had been satis-

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[1] Contribution from the Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Published by permission of the Director. Received for publication August 14, 1929.

[2] Assistant Agronomist.

[3] Reference by number is to "Literature Cited," p. 180.

factorily used, it was supposed that the difficulty was in the apparatus or technic used. These were such as to make it easy to overlook the rapid drift in potential which characterizes soils giving improper readings with the quinhydrone electrode, observance of which probably would have given a more correct clue as to the difficulty.

Work was done in June and July, 1928, using the Princeton soils and other soils on hand from various parts of Kentucky, which showed rather clearly that the difficulty was not in the technic or apparatus used. Brief reference was made to this work in part I, page 38, of the 41st annual report of the Kentucky Experiment Station. This was further confirmed by work on samples of soils which, on request, E. F. Snyder, of the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture, and L. D. Baver, of the Ohio Experiment Station, kindly sent the writer, and in connection with which they furnished the pH values determined by themselves, using the quinhydrone and hydrogen electrode methods, with good agreement between the two methods. These values were determined by the writer with good agreement between the two methods and with fair agreement with the corresponding values found by Baver and Snyder, as shown in Table 1.

TABLE 1.—*The pH values of soils from Baver of the Ohio Experiment Station and Snyder of the U. S. Dept. of Agriculture.*

Soil	Determinations by Baver or Snyder		Determinations by the writer	
	Quinhydrone electrode	Hydrogen electrode	Quinhydrone electrode	Hydrogen electrode
Baver No. 1	3.99	4.05	3.82	3.91
Baver No. 2	5.10	5.14	4.87	4.82
Baver No. 3	5.41	5.54	5.22	5.29
Baver No. 4	6.08	6.07	5.97	5.98
Baver No. 5	6.58	6.40	6.44	6.11
Baver No. 6	8.10	8.11	8.20	8.11
Snyder's Norfolk fine sandy loam	4.73	4.75	4.41	4.51
Snyder's Portsmouth fine sandy loam	5.60	5.68	5.27	5.34

Samples of four Kentucky soils with the pH values determined by the writer, using the quinhydrone and hydrogen electrodes, were sent to Baver at this time. Baver (1) referred to these soils in a footnote in a recent paper.

Considerable work, mainly on Kentucky soils, was done in the latter part of 1928 and early in 1929, comparing the quinhydrone electrode method with the hydrogen electrode method and with a colorimetric method and obtaining information as to the cause of the higher pH values found by the quinhydrone method than by the other methods.

The pH values found by the three methods for a number of soils are given in Table 2. It is believed that these soils fairly well represent the bulk of the upland surface soils of the state. It will be noted that with none of these soils is there good agreement between the quinhydrone electrode and the other methods. In later work, soils from Kentucky were studied with which the quinhydrone electrode gave good agreement with the other methods. Results from these soils will be given later in the paper. Doubtless there are numerous soils in Kentucky where such agreement would occur. The important thing, however, is that in determining the hydrogen-ion concentration of a number of soils selected in other connections and for the most part to represent average upland surface soils in Kentucky, most of them being from soil experiment fields, the quinhydrone electrode gave results which, in nearly all cases, were higher than those obtained with the hydrogen electrode or colorimetric methods, the difference reaching a maximum of 1.5 pH with some soils and a difference of 1.0 pH being not uncommon. It will be noted that the difference was less in the limed than in the unlimed soils. It will later be noted that the difference is likely to be less with subsoils than with surface soils.

TABLE 2.—*The pH values of representative Kentucky surface soils determined by the quinhydrone electrode, hydrogen electrode, and colorimetric methods, showing the lack of agreement of the quinhydrone with the other methods.*

Sample No.	Description of sample	Soil suspensions Quinhydrone electrode	Soil suspensions Hydrogen electrode	Soil filtrates colorimetric
1	Greenville soil experiment field, manure treatment	6.93	—	5.75
2	Greenville soil experiment field, manure and superphosphate treatment	6.42	5.37	5.40
3	Greenville soil experiment field, manure, limestone and superphosphate treatment	7.50	6.50	6.40
4	Lexington soil experiment field, crop residue treatment	5.37	4.91	5.10
5	Western sub-experiment station field, no treatment	6.56	5.55	—
6	Western sub-experiment station field, no treatment*	6.41	5.27	– –
7	Western sub-experiment station field, limestone and superphosphate treatment	7.07	6.49	6.55
8	Campbellsville soil experiment field, manure treatment	6.39	5.25	5.40
9	Campbellsville soil experiment field, manure and limestone treatment	7.13	6.27	6.10
10	Berea soil experiment field, no treatment	5.84	5.01	5.30
11	Soil from Pendleton County	5.46	4.99	5.10
12	Soil from Pendleton County	7.34	—	7.10
13	Mayfield soil experiment field, manure and superphosphate treatment	6.10	5.23	—

*Soil from another check plat than 5.

The hydrogen-ion concentration of four soils was determined, using the quinhydrone and hydrogen electrodes on the filtrates as well as on the suspensions. Colorimetric determinations were also made on the filtrates. The results are reported in Table 3. The same ratio of soil and water (1:1.5) was used in all these determinations. The quinhydrone electrode results on the filtrates agree fairly well with the other methods. Satisfactory hydrogen electrode readings on the filtrates were difficult to obtain on account of their poorly buffered nature. A fair check on the fact that the hydrogen-ion concentration of the filtrate had not changed during the hydrogen electrode reading due to passage of hydrogen was obtained by running a colorimetric determination on the filtrate from the hydrogen electrode vessel at the close of the determination and comparing with the colorimetric result on a portion of the original filtrate (before the hydrogen electrode determination). Pierre (6) and others report difficulty in using the hydrogen electrode with soil filtrates. Olsen and Linderstrom-Lang (5), however, mention no difficulty in this connection.

TABLE 3.—*The pH values on soil suspensions by the quinhydrone and hydrogen electrode methods, and on the filtrates by these two methods and by the colorimetric method, showing lack of agreement of the two methods with the suspensions and fair agreement of the three methods with the filtrates.*

	Suspensions		Filtrates		
Soil No.*	Quinhydrone electrode	Hydrogen electrode	Quinhydrone electrode	Hydrogen electrode	Colorimetric
2	6.42	5.37	5.29	5.23	5.40
3	7.50	6.50	6.26	6.81	6.50
8	6.39	5.25	5.41	5.70	5.40
9	7.13	6.27	5.96	6.62	6.20

*For description of samples, see Table 2.

Soils with which the quinhydrone electrode gave higher pH values than the hydrogen electrode show a characteristic drift in potential with the quinhydrone electrode. The drift with the Kentucky soils was much greater than that studied by Baver (1), and probably more nearly similar to that in the manganiferous soils reported by McGeorge (4), though the actual drift in potential of these soils was not given. The drift in potential of three Kentucky soils is given in Table 4.

As McGeorge concludes, the drift in potential is sufficient warning when the quinhydrone method is not applicable to any soil. The type of apparatus and technic used, however, must be such as to favor easy observance of the drift. With most soils, the larger part of the drift takes place in the first minute after adding the quinhydrone. Baver (1) suggests that the quinhydrone method can be used with sufficient accuracy for practical purposes on such soils by

TABLE 4.—*Drift in potential of three soils with the quinhydrone electrode method.*

Minutes from time of adding quinhydrone to that of reading	Potential in volts	pH for high and low potentials
	Surface Soil from Pendleton County	
0*	0.162	4.92
½	0.157	
1½	0.146	
2	0.140	
2½	0.137	
5	0.129	
7	0.128	
9	0.127	
10	0.126	5.53
11	0.126	
	Soil No. 5 (Table 1)	
0*	0.130	5.46
½	0.100	
1	0.065	
1½	0.059	
2½	0.055	6.73
3½	0.055	
	Soil No. 2 (Table 1)	
0*	0.140	5.29
½	0.105	
1	0.085	
2	0.078	
3	0.074	
4	0.073	6.42
5	0.073	

*Read as soon as possible after adding quinhydrone.

using the first reading. The first reading would be nearer accurate, but with the rapid drift experienced, the quinhydrone electrode method can hardly be considered satisfactory for such soils even for practical purposes.

It would perhaps be natural to assume that the incorrect results with the quinhydrone electrode method were due to the manganese content of the soils. Shedd (8) has reported work on the manganese content of Kentucky soils showing considerable amounts present in many soils. He reported the percentages present in surface soils to vary from 0.005 to 0.331, and in subsoils from 0.002 to 0.264. The average amount found in cultivated surface soils was 0.119%, and in cultivated subsoils 0.059%. There is no reason to believe, however, that the manganese content of Kentucky soils is widely different from that of soils in many other sections. Baver, in correspondence in August, 1928, suggested that manganese might be the cause of the difficulty.

Toward the close of the work reported in this paper, the paper by McGeorge (4) appeared in which definite correlation was shown between the manganese content of Hawaiian soils, believed to be in the dioxide form, and the extent to which pH values determined by the quinhydrone electrode were higher than the corresponding hydrogen electrode values. Limited work by the writer indicates rather clearly that manganese is the cause of the difficulty in the Kentucky soils, but the corrrelation of difference between quinhydrone and hydrogen electrode readings with total manganese content is not close.

Shedd kindly furnished the writer with samples of some of the soils for which he had determined total manganese content. The hydrogen-ion concentrations of these samples were determined, using the quinhydrone electrode method on soil suspensions and the colorimetric method on soil filtrates. The results, together with the percentages of manganese found by Shedd, are given in Table 5. Possibly absence of appreciable drift (change in pH value in the table) is as good an indication of a correct pH value with the quinhydrone electrode as agreement with the colorimetric result. With some of the soils, in particular No 828, there is no clear explanation for the difference in quinhydrone and colorimetric results.

TABLE 5.—*Total manganese determined by O. M. Shedd, Kentucky Experiment Station, and the pH values found in the present work by the quinhydrone and colorimetric methods for a number of Kentucky soils.*

Soil No.*	Manganese %	Quinhydrone on suspensions			Colorimetric
		At once	After equilibrium	Drift	
		pH	pH	pH	pH
752^2	0.198	5.29	5.36	0.07	5.55
818^1	0.194	5.12	6.03	0.91	5.50
753^2	0.160	5.41	5.36	—0.05	5.45
820^1	0.136	5.88	6.37	0.49	5.40
763^1	0.050	4.70	4.75	0.05	4.70
761^1	0.047	4.61	4.63	0.02	4.70
826^1	0.038	6.27	6.24	—0.03	5.90
828^2	0.022	6.64	6.70	0.06	6.25

*Exponent 1 = surface soil, 0–6 inches; 2 = subsoil, 6–18 inches.

The total manganese content of certain soils was determined in the present study.[4] The results, together with the H-ion concentration results, are given in Table 6.

In the results reported in Tables 5 and 6 any soil showing significantly higher pH value with the quinhydrone electrode method than with the other methods (or in the case of Shedd's soils, showing considerable drift with the quinhydrone electrode) had a manganese content of 0.10% or above. It will be recalled that Shedd found the average manganese content of Kentucky surface soils to be 0.119%. Not all soils with this amount of manganese, however, gave unsatisfactory readings with the quinhydrone electrode method. Soil No.

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[4] A chlorate method devised by E. M. Emmert, Dept. of Horticulture, Kentucky Experiment Station, was used in these determinations. The method probably will be published in the near future.

TABLE 6.—*Total manganese and the pH values determined by the quinhydrone and hydrogen electrode methods for certain Kentucky soils.*

Soil	Manganese	Quinhydrone electrode method	Hydrogen electrode method
	%	pH	pH
5 (Table 2)	0.377	6.56	5.55
Subsoil of preceding*	0.270	7.13	5.89
Surface soil, no treatment, Greenville experiment field	0.183	6.68	5.32
Subsoil of preceding*	0.065	4.88	4.87
Surface soil from Pendleton County	0.100	5.53	5.06
Subsoil of preceding*	0.054	4.70	4.69

*6–18 inches.

752 in Table 4, with a manganese content of 0.198%, and soil No. 753 in the same table, with 0.160%, both gave satisfactory quinhydrone electrode readings. These were subsoils. Subsoils are more likely to give correct readings with the quinhydrone electrode than surface soils, due frequently to a lower content of manganese, but also the limited results rather strongly suggest that the manganese in subsoils is not as likely to be in the form to cause the difficulty as in the case of surface soils.

The effect of liming in decreasing the extent of difference between quinhydrone and hydrogen electrode pH values, as shown by the results in Table 1, is also to be recalled in this connection. In Table 6, in the case of surface soil No. 5 and the corresponding subsoil, the manganese content of the subsoil was lower than that of the surface soil, but for some reason the difference between quinhydrone electrode pH value and the hydrogen electrode pH value was greater in the case of the subsoil than of the surface soil.

Some work was done adding manganese compounds to standard buffer solutions and to soils which in their natural condition gave correct quinhydrone electrode results, to find out the drift produced. Manganese dioxide produced a drift in the acid direction (lower pH value, higher potential using the calomel electrode) in the case both of a standard buffer solution of pH 6.90 and in the case of Baver No. 4 soil. The drift was small in the case of the standard buffer solution. It was larger with the soil, the pH value on adding the quinhydrone being pH 4.78 where 0.2 gram manganese dioxide had previously been added and reaching constant potential in 3 minutes with a value of pH 3.65. This drift is opposite to that of the soils which gave incorrect reading with the quinhydrone electrode method.

Potassium permanganate gave a drift in the same direction as that in the soils. This was true with standard buffer solutions and with soils. The Kentucky soils differed in this respect from the

Hawaiian soils (4), where manganese dioxide gave a drift in potential in the same direction as that in the soils.[5] The limited results with the Kentucky soils indicate that it is not enough to have a high total manganese content to give too high pH values with the quinhydrone electrode, but that the manganese must be present in a form or forms more highly oxidized than the dioxide form.

In the beginning of this work it was thought that perhaps additions of fresh quinhydrone, after a constant potential had been reached with the usual addition, would bring the reading wholly or to some extent back to the correct one, but this was found not to occur. Additions of fresh quinhydrone amounting to several times the first application changed the potential reached very little or none at all. It would seem that, if the difficulty is due to manganese present in a particular form, it might be possible to change this form to some other which would not interfere with the use of the quinhydrone electrode and that perhaps action between the objectionable form of manganese and quinhydrone itself might accomplish this, but such does not seem to be the case. Some effort was made to accomplish this in other ways, but with no success.

The fact that the quinhydrone electrode method gives correct results with the soil filtrates from soils where the readings on suspensions are not correct indicates either that the objectionable form of manganese is not soluble or, if soluble, rapidly changes to an unobjectionable form after removal from the soil. In this connection, as determined by work with four soils which gave too high pH values with the quinhydrone electrode, if the usual soil-water and quinhydrone mixture is prepared and then filtered, the reading on the filtrate without or with addition of fresh quinhydrone is practically the same as the reading after equilibrium is reached when the determination is made on the suspension in the usual way. This is further very largely true whether the filtering is done in a few minutes after the soil-water and quinhydrone suspension is made or whether as much as several days is allowed to go by before filtering and getting the reading.

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[5] While this paper was in press, a paper by Heintze and Crowther on "An error in soil reaction determinations by the quinhydrone method" appeared in the Transactions of the Second Commission of the International Society of Soil Science (Vol. A, pp. 102–110). They state that additions of a little MnO_2 to solutions and to "good" soils change the reaction towards the alkaline side, agreeing with McGeorge. In some further work by the writer, since Heintze and Crowther's paper appeared, additions of MnO_2 to a standard buffer solution of pH 6.90 were observed to give a drift only towards the acid side with the quinhydrone electrode. When a little MnO_2 was added to a standard buffer solution of pH 4.90, the drift was towards the alkaline side; when a considerable amount of MnO_2 was added, the drift was first towards the alkaline side then towards the acid side; while additional amounts of quinhydrone changed the drift again towards the alkaline side. Baver No. 4 sample of soil had been exhausted, but work was done with a few other "good" soils of pH value around 5.0. The addition of small amounts of MnO_2 gave a drift towards the alkaline side with the quinhydrone electrode. Addition of considerable amounts of quinhydrone gave a drift first towards the alkaline side then towards the acid side, with additional amounts of quinhydrone changing the drift back again towards the alkaline side. These observations apparently fit in with Heintze and Crowther's suggestion that quinhydrone reduces MnO_2 to manganous hydroxide. When the MnO_2 addition is in excess of the reducing ability of the quinhydrone present, the drift, at first towards the alkaline side, reverses and goes towards the acid side.

A ratio of 1 of air-dry soil to 1.5 of water was used in the work of the three methods reported in this paper. In most of the work 10 grams of soil and 15 cc of water were used. In the quinhydrone readings, the soil and water were placed in the electrode vessel, connection made with the calomel cell by means of an agar bridge, the mechanical shaker started, and, after thorough mixing of soil and water had come about, 0.1 gram of quinhydrone added. Detailed procedure for the hydrogen electrode and colorimetric methods are given in a former paper (3).[6]

Hydrogen-ion concentration determinations of soils are at times very unsatisfactory by whatever method used, but for the most part the extreme precautions frequently suggested in the literature are not required for satisfactory work, such as the use of chemicals of a very high degree of purity and extreme cleanness of electrodes, and difficulties, when encountered, are frequently not solved by these extreme precautions. In selecting a method for the routine determination of hydrogen-ion concentration of soils where many of the soils can not be read by the quinhydrone electrode method, the colorimetric method is to be recommended.

SUMMARY

The quinhydrone electrode method gave higher pH values than the hydrogen electrode or colorimetric methods on samples of Kentucky surface soils which should fairly accurately represent most of the surface soils of the state. The maximum difference found was 1.5 pH. A difference of 1.0 pH was not unusual. Soils giving incorrect readings with the quinhydrone electrode method in suspensions gave

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[6] Pierre and Fudge (7) have recently called attention to the necessity of adjusting the reaction of indicator solutions for use in soil filtrates to near the neutral point for the respective indicator solution before satisfactory results can be secured. They apparently overlooked an earlier, though perhaps not very clear, reference by the writer (3) to the necessity of doing this.

correct readings by this method when the filtrates were used. It was indicated that the incorrect readings with the quinhydrone electrode in soil suspensions were due to the presence of manganese in some particular form or forms, apparently more highly oxidized than the dioxide form, and were not directly correlated with total manganese content of the soils. A rapid drift in potential with the quinhydrone electrode is a warning when this method is not accurate in soil suspensions. The colorimetric method is suggested as a satisfactory method for routine determinations.

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EFFECTS OF CROPPING ON THE PHYSICAL CONDITION OF THE SOIL WITH DATA ON YIELDS[1]

JOHN W. GILMORE[2]

The purpose usually stated for changing crops on the land, or for changing soil treatments, are, first, for reasons relating to the plant food constituents of the soil; second, for reasons relating to the control or eradication of insect, fungous, and weed pests and other deterrents; and third, for reasons relating to the economic management of the land.

These purposes are well expressed, but another set of reasons might well be added, namely, those relating to the physical condition of the soil. That the physical condition of the soil has important influences on the productivity of the land is a well recognized fact, and sometimes the so-called "fertility" of the land may be more largely a function of the physical condition than of the chemical composition of the soil.

These influences are generally due to moisture and air relationships; and these in turn modify temperature, biological, and chemical conditions existing in the soil. As a general rule, the characteristic of the soil referred to under the term "physical condition" is its structure. Within the same soil type variations in structure, at least so far as tillage is concerned, are due largely to cohesion of the soil particles, their plasticity, and to friction on the contact surfaces of the implement used. These characteristics, in turn, are related mainly to organic matter, colloid, and moisture contents.

The influence of crops and crop culture on the physical condition of the soil, and especially on its structure, is a subject full of complexes and interrelationships. The decaying roots and the consequent soil color; the presence of added or residual organic matter; the time, frequency, and type or process of stirring the soil; and the nature of the crop grown, all have a bearing on the interesting and important subject of structure or tilth of the soil. The physical condition of the soil may be measured by the draft of the plow, harrow, or other implement by which the soil is stirred, and this figure may then be correlated with the several factors enumerated above.

A considerable amount of work has been done on the factors that influence the draft of the plow and other cultivating implements under field conditions, but most of the work done along this line has been related to the moisture content of the soil, the depth of operation, the friction of the contact surfaces, and the rate and distance of soil movement. Recently, however, there have appeared several papers based upon work at the Rothamsted Experiment Station designed to throw some light on the draft of the plow as it is related to some of the physical qualities of the soil.

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[1] Contribution from the Department of Agronomy, California Agricultural Experiment Station, University Farm, Davis, Calif. Grateful appreciation of the author is expressed to Professors A. H. Hoffman and E. J. Stirniman for assistance in these tests. Received for publication August 21, 1929.

[2] Agronomist.

In 1925, Haines (2)[3] determined by the Atterberg method that laboratory results on cohesion studies checked closely with those obtained in the field by dynamometer trials. He showed that there was an inverse relationship between cohesion and moisture content. His experiments on surface friction showed that variation was caused by the factors of type and moisture content of the soil. For light soils with a minimum of plastic properties the friction remained about constant from dry to about 12%. Above that moisture content the moisture wet the surface and the friction increased. At about 17% of moisture the wetting had the effect of lubricating the surface and the friction decreased. Heavy soils with marked plastic qualities showed two maxima in the friction curve, one when the soil became wet but not sticky and the other when the soil became wet enough to be sticky. This corresponded to a stage of saturation beyond which the particles began to float, and thus to lose their plastic and coherent qualities.

Keen and Haines (3), in studies made in the field with plow and dynamometer, showed that the draw-bar pull of a plow was very closely related to the clay content of the soil, and was modified by crop growth and drainage. While some variation seemed to be due to the manurial treatment, yet this was small compared to the distribution of clay.

In 1911, Noll (4) obtained the draft of a plow as it crossed a series of the fertilizer plats which were laid out at the Pennsylvania Experiment Station in 1882. The soils of these plats are of both the Hagerstown silt and clay loam. These plats have been systematically treated with various fertilizers and manure, and cropped in rotation to corn, oats, wheat, and hay. Summarizing the draft trials the author states, "When the average draft for all of the plats is studied, it seems that the fertilizer treatment has had little influence on the soil structure. The draft has been about the same on four manured plats as on complete commercial fertilizer plats alternating with them. The presence of more organic matter in some of the soils has slightly lightened their draft."

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[3] Reference by number is to "Literature Cited," p. 188.

In 1912, a series of plats were laid out at University Farm, Davis, California. These plats were designed, among other purposes, to bring out information on the influences of continuous cropping to grain, the alternation of a grain crop with summer fallow, the influence of a green manure crop on the grain crop to follow, and the effect of a 4-year rotation including milo and summer fallow. The plats were one-twentieth acre in area, 18 by 121 feet with an alley of 3 feet between each one. They were arranged in such a way that each treated plat lay adjacent to a check plat.

In the fall of 1925 at the time of preparing the plats for planting a three-bottom plow was attached to a small tractor, and this drawn across the plats at a depth of 10 inches. In the hitch was arranged a dynamometer for the purpose of recording the draft of the plow as it crossed the plats from one end of the series to the other.

The rainfall at Davis averages 16.87 inches and occurs almost entirely in the months of November to April, 89.1% of the total falling during that period. Consequently, surface soils at this station approach the condition of air-dryness at the close of the dry period. At the time of this test, December 5, 2.4 inches of rain had fallen and had, therefore, wet the soil to a depth of about 8 inches. This wet portion of the soil contained 18.2% of moisture (average of 10 samples taken from various plats throughout the series). The plows were set at a depth of 10 inches, just below the depth of moisture penetration. This was done in order that the plane of cleavage might be in the dry soil. The speed of the plow was about 4 miles per hour.

For the purpose of illustrating the system of cropping on the draft of the plow a few groups of these plats have been chosen. Others in the series brought out similar results. For instance, six plats (32–37 inc.), which comprised a 4-year rotation of barley, peas, wheat, and fallow, with two check plats, gave an average draft for the treated plats of 2,252.0 pounds, while the draft on the checks averaged 2,549.6 pounds.

Fig. 1 shows graphically the variation in the draft of the plow as it crossed plats 3, 4, 5, and 6. These plats had for a period of 12 years been managed as follows: Plat 3 continuously planted to wheat (check); plat 4, alternate wheat and cultivated fallow; plat 5, alternate wheat and cloddy fallow; plat 6, check, treated as plat 3. The year of this test (1925) all plats were in wheat. The fallow was made in March or early April of the year following the crop of wheat. Plat 5 was left cloddy just as plowed, while plat 4 was disced after plowing in order to bring the surface to a moderate state of tilth. Weeds seldom germinated on the plats, but if they did they were hoed while very small, hence they did not interfere with the moisture content of the soil. On all four plats some volunteer grain and winter weeds would be plowed under, in addition to the stubble of the previous crop.

The dynamometer was calibrated to the constant of 82.63 pounds for each mm of displacement from the base. This and the following curves show considerable irregularity; but this is probably due to the characteristics of the soil upon which these tests were made, for it has a tendency to bake and crack during the summer and to break up cloddy in the fall. The soil of this group of plats is classified by the U. S. Bureau of Soils as Yolo loam, which has the following mechanical composition expressed in percentages of the total: Fine gravel, 0.1; coarse sand, 0.4; medium sand, 0.9; fine sand, 9.5; very fine sand, 27.3; silt, 43.3; and clay, 18.2.

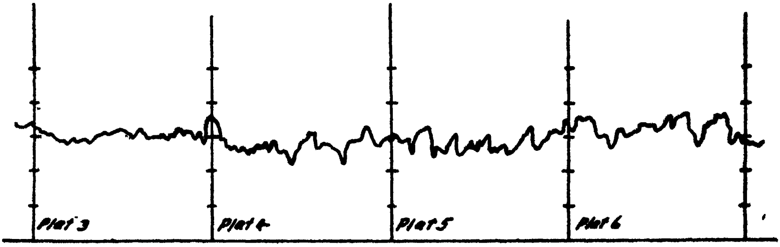

FIG. 1.—Showing the draft of the plow as it crossed fallow and continuously cropped plats. (See Table 1 for figures of yield and draft.)

The yield of these plats in pounds of wheat per acre and the draft of the plow is given in Table 1.

TABLE 1.—*Showing the relation of treatment to yield of wheat and draft of plow.*

Plat No.	Treatment	No. of crops	Average yield in pounds per acre 1st 6 year	d 6 years	12-year period	Draft of plow, pounds
3	Check	12	1,983.6	1,141.0	1,562.3	2,436.7
4	Fallow-wheat	6	2,533.0	2,470.2	2,501.6	2,155.0
5	Fallow-wheat	6	2,562.2	2,501.6	2,531.9	2,268.2
6	Check	12	2,128.4	1,017.7	1,573.0	2,503.7

Thus, it will be seen that the draft is materially less on the treated plats than it is on the check plats. No doubt but that the breaking and the air-drying of the soil on the fallow plats modified the coehsion of the soil on these plats to a considerable extent. It is believed, also, that this poor physical condition or compaction had a material influence on the yields of the check plats. This, however, may account only partly for the rapid and marked decline in the second period. The other factor involved is believed to be a below-normal rainfall for the period. The seasonal rainfall for the entire period was 16.80 inches, which is 0.14 inch below the seasonal normal. The average seasonal rainfall for the first 6-year period was 18.80 inches, while that for the second 6-year period was 14.81 inches. It is very difficult however to estimate the influence of rainfall on the yield of grain at Davis, for the temperature and humidity of the spring months have a marked influence. It is believed that the difference in rainfall of the two periods had little or no influence on the physical condition of the soil as measured by draft of the plow, for in any event the soil is in about the same condition of dryness at the end of the dry season.

Fig. 2 shows graphically the variation of the draft of the plow as it crossed plats 18, 19, 20, and 21. These plats had for the same period of time management similar to those above; except that there were two years in wheat and one of fallow on the treated plats, while the check plats, 18 and 21, were continuously cropped to wheat.

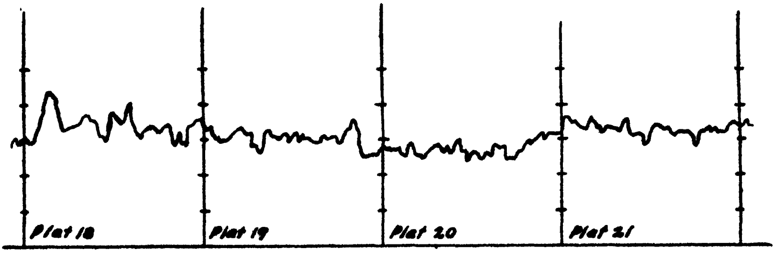

FIG. 2.—Showing the draft of the plow as it crossed three-year rotation and continuously cropped plats. (See Table 2 for figures of yield and draft.)

These plats, however, occurred on Yolo silt loam which differs from the Yolo loam in that it has less sand and more silt and clay. The mechanical analysis is as follows, expressed in percentages of the total: Fine gravel, 0.0; coarse sand, 0 1; medium sand, 0.1; fine sand, 1.2; very fine sand, 5.0; silt, 69.1; and clay, 24.4. This increase in clay may account for the slightly higher draft of the checks of this group as compared with the checks of the above group, but the reason for the difference between the treated plats 19 and 20 is obscure. It might be expected that two crops of wheat between fallow would increase the draft on the treated plats 19 and 20, but such does not seem to be the case. The year of this test (1925) all plats were in wheat. The yield of this group of plats with the draft of the plow is given in Table 2.

TABLE 2.—*Showing the relation of soil treatment to yield of wheat and draft of plow.*

Plat No.	Treatment	No. of crops	Average yield in pounds per acre 1st 6 years	 2nd 6 years	 12-year period	Draft of plow, pounds
18	Check	12	1,672.8	1,052.4	1,362.6	2,679.7
19	Wheat-wheat-fallow	8	2,315.1	1,784.7	2,049.4	2,340.1
20	Fallow-wheat-wheat	8	2,276.3	1,992.2	2,134.3	2,081.4
21	Check	12	1,794.4	1,170.1	1,482.3	2,507.8

The same inferences may be drawn from these figures as from those of the preceding group. It will be noticed, however, that in this group the decline in yield between the first and second periods on the treated plats is greater than in the group of plats above.

Fig. 3 indicates the draft of the plow as it crossed plats 29, 30, and 31. Plats 29 and 31 have been in a four-year rotation of wheat-fallow-barley-milo during the period of 12 years. Thus, for two years out of the four the soil on these two plats has been cultivated and kept loose. This seems to have had a tendency to lower the draft of the plow on these plats. The year of this test (1925) plat 29 was fallow and plat 31 in wheat.

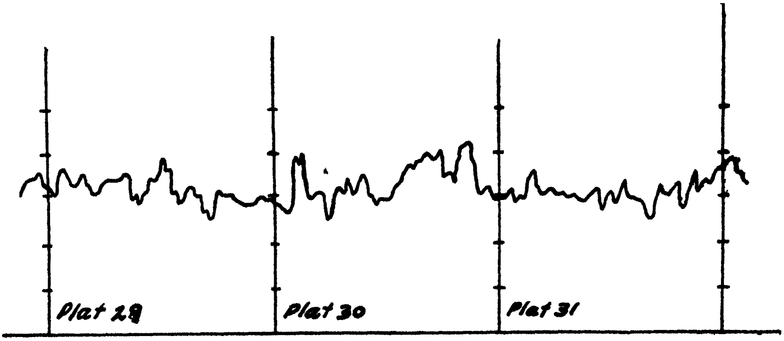

FIG. 3.—Showing the draft of the plow as it crossed four-year rotation and continuously cropped plats. (See Table 3 for figures of yield and draft.)

Table 3 shows the yield and draft of the plow on these plats during the 12 years of treatment. The yields of the treated plats for the two periods are not given for the reason that these plats came into wheat only three times during the entire period.

TABLE 3.—*Showing the yield of wheat and draft of plow on plats in rotation.*

Plat No.	Treatment	No. of crops	Average yield in pounds per acre 1st 6 years	2nd 6 years	12-year period	Draft of plow, pounds
29	Rotation	3	———	———	1,726.0	2,478.0
30	Check	12	1,693.5	920.5	1,307.1	2,564.0
31	Rotation	3	———	———	1,891.9	2,389.5

The differences in draft in this group of plats are not so great as in former groups. This may be caused partly by the fact that the yields of wheat on the rotation plats are also not so great as on the treated plats of the former groups. It would seem that so far as draft is concerned the rotation plats are not very much better in physical condition than the continuously cropped plats.

Fig. 4 shows the draft of the plow as it crossed plats 38, 39, and 40. Plats 38 and 40 had a crop of peas every other year alternating with wheat. The peas were turned under each year in March or April, according to the season, and the land left in cultivated fallow the remainder of the year. Both the Yolo loam and the Yolo silt loam are comprised within the limits of this group of plats, yet the strip plowed was so arranged that it crossed only the loam, hence its physical composition is similar to that of the first group.

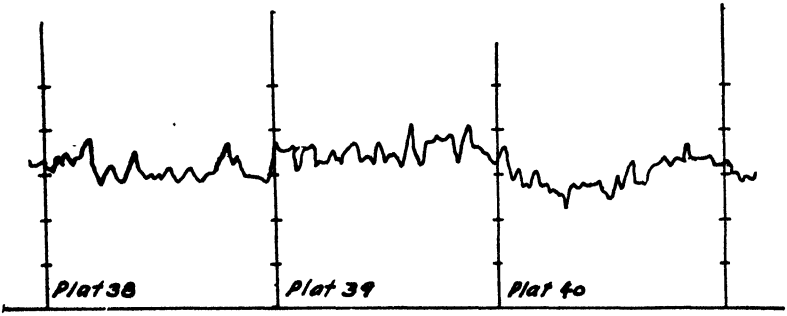

FIG. 4.—Showing the draft of the plow as it crossed green manure and continuously cropped plats. (See Table 4 for figures of yield and draft.)

The yield of peas on plats 38 and 40 varied from year to year on account of stand and climatic conditions, the variation being from 3 to 7 tons of green material per acre. The average was about 4.6 tons. As indicated by the figures in Table 4, the wheat crops following this treatment were materially augmented. This year plat 38 was in peas, while plat 40 was in wheat.

TABLE 4.—*Showing the influence of green manure treatment on the yields of wheat and the draft of plow.*

Plat No.	Treatment	No. of crops	Average yield in pounds per acre 1st 6 years	2nd 6 years	12-year period	Draft of plow, pounds
38	Wheat-peas	6	2,846.8	2,369.4	2,608.1	2,394.6
39	Check	12	1,621.8	1,026.6	1,324.2	2,564.0
40	Peas-wheat	6	1,582.6	2,280.0	1,932.3	2,249.2

All of the data taken together indicate that changing the crops on the land and thus altering the treatment or cultivation of the soil has a tendency to modify the physical condition of the soil as it affects the draft of the plow. But whether it is the crop grown or the soil treatment that is the more important factor is difficult to ascertain. It may be that during the period the organic matter content of the soil on the several plats studied was modified, but no data were obtained to check this point. That the physical condition of the soil of the check plats deteriorated was observed by workmen who plowed these plats each fall for several years before these tests were made. Each year the plowmen observed that the fell of the plow indicated the check plats as it crossed them, and the effect grew more noticeable each year.

Aside from the marked differences in both draft and yield between the check and treated plats, it might be stated that the check plats also showed a marked infestation of weeds, including especially wild oats and morning glory.

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NOTES

A USEFUL HOLDER FOR PLAT STAKE LABELS

The problem of labelling plats is always of concern to agronomists and plant breeders. A metal holder for card labels which can be attached to an upright wooden stake was designed several years ago at the Ft. Hays Branch Experiment Station, Hays, Kansas. Inquiries have been received from several investigators who have seen the holder in use and it seems desirable to describe it.

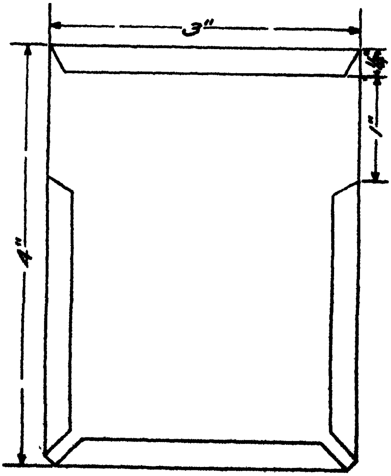

Fig. 1.—Specifications for a plat stake label holder.

The label holder, shown in Fig. 1, can be made from galvanized iron (No. 28 gauge, or thereabouts) at a cost of from 3 to 4 cents each, or even less if scrap material is used. The guides should not be less than $\frac{3}{16}$ to ¼ inch in width, or wider if the holders are of large size. One inch of each of the side guides along the upper portion of the holders is cut away to permit the label to be inserted easily. It is essential to have also a guide at the top of the older to prevent the label from "creeping" out. A label can be removed easily from the holder by lifting the edge at one of the upper side openings, but it will rarely fall out accidentally.

The holders should be fastened to the stakes by two nails clinched on the back. Screws tend to work loose when the stakes are driven into the ground. The tops of the holders should be placed 1 inch below the tops of the stakes to prevent mutilation when the stakes are driven into the ground.

One of the chief advantages in using label holders of the type described is that at threshing time labels can be removed quickly without mutilation and placed inside the sack of grain. Stakes also can sometimes be used for two crops the same season.—A. F. SWANSON, *Associate Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture, Hays, Kans.*

A NEW VARIETY OF ALFALFA

Because of the widespread interest in the stand losses of alfalfa in some sections of the country due to winterkilling and bacterial wilt (*Aplanobacter insidiosum* L. McC.), attention is directed to the discovery and naming of a relatively resistant new variety by the Nebraska College of Agriculture. Field experiments and observations have proved it to be very desirable from all production aspects in this region. "Hardistan" is the name assigned, implying hardiness of stand and probable Turkestan origin. Arrangements have been made for increasing the limited supply of seed available and for certified production by members of the Nebraska Crop Growers' Association.

The immediate seed source of this new variety is an old superior field of alfalfa belonging to Arnold Brothers in Dawson County, Nebraska. Special attention was first called to this field by County Extension Agent A. R. Hecht, who described it as the most outstanding field known in Dawson County. In 1927, 16 years after sowing, it was recognized as having a practically perfect stand aside from deprivation by pocket gophers. Hecht investigated the history of the seed from which this field had been sown and found it was secured from a seed house as Turkestan seed.

Seed from the Arnold Brothers field was obtained by the Experiment Station and planted in duplicated field plats in the spring of 1922 in comparison with other standard varieties and regional strains of common alfalfa. Hay yields have been determined each year beginning with 1923. The yielding ability of Hardistan is satisfactorily established by 4% superiority during the 7-year period over Nebraska Common, which was grown as a check, compared with 5% superiority for the Grimm variety. Outstanding winterhardiness is evidenced by a full and uniform stand 8 years after sowing, the stand being superior to that of all other sorts. A dedetermination of wilt infection in the various plats in 1928 revealed 71% of infected plants in the Nebraska Common, 67% in Grimm, and 28% in the Hardistan. The original field of Arnold Brothers, as well as other fields in Dawson County which have been sown from Arnold Brothers seed, show materially less wilt infection than do neighboring fields of Common and Grimm alfalfa.

In appearance and growth habits Hardistan closely resembles the Common variety. Although believed to have originated in Turkestan, it does not have the specific vegetative characteristics which are usually regarded as featuring typical Turkestan alfalfa.

Prior to being named, agronomic results with this variety were reported in Nebr. Agr. Exp. Sta. Res. Bul. 36 and Bul. 222, under the designation of Common alfalfa, from Dawson County.—T. A. KIESSELBACH, ARTHUR ANDERSON, and G. L. PELTIER, *Dept. of Agronomy, Nebraska Agr. Exp. Sta., Lincoln, Nebr.*

BOOK REVIEWS

THE NATURE AND PROPERTIES OF SOILS

By T. Lyttleton Lyon and H. O. Buckman. New York: The Macmillan Co. 428 pages, illus. Ed. 2. 1929. $3.50.

The first edition of this useful textbook was published in 1922. It was reprinted in 1923, 1926, and 1927 with so few changes (if any) that no new copyright has been claimed until 1929. This new edition, however,—altho no mention of the fact is made in the Foreword—is actually a complete revision of the book from beginning to end. The titles of the chapters have been changed throughout and scarcely a paragraph heading is identical with the corresponding one in the first edition. That a complete revision was necessary is self-evident if one will recall the tremendous progress that has been made during the intervening seven years in such subjects as hydrogen-ion concentration, colloid chemistry, and soil classification.

The most striking difference between the two editions is that the text of the new book contains only 405 pages, while that of the original edition covered 560 pages apparently averaging the same number of words each as those in the revised edition. The number of chapters has been reduced from 26 to 18. This condensation seems to have been effected in order to make the book more practical as a text for college classes. The space has evidently been saved largely by rearranging the material so as to present it more concisely; for when any particular chapter in the new edition is compared with the section or sections of the first which treat the same subject, it is found that more rather than less detail is present in the new book.

One can, nevertheless, find certain chapters in the first edition (e. g. Colloidal Matter of the Soil, Soil Heat, Soil Air, The Absorptive Properties of Soils, and Chemical Analysis of Soils) which have no counterparts in the new and the subject matter of which is referred to but briefly in different sections of the new text. This fact is not mentioned as a criticism, however, for it is believed that the authors have been very successful in bringing the book up-to-date and putting it in a more practical form than the original edition. (H. J. C.)

MICROBIOLOGY

By B. F. Lutman. New York: McGraw-Hill Book Co. X+495 pages, illus. 1929. $4.

A new and distinctive plan of organization definitely sets this book apart from the usual book on microbiology or bacteriology. With the exception of a few general chapters, the morphological characters, the physiological activities, and the practical importance of microorganisms have been presented by the discussion of a relatively few "type" species. In many respects, the arrangement is admirable. The general discussions of microbial characters have been definitely correlated to individuals in a way to arouse and hold the reader's interest. This type of presentation, however, necessarily places emphasis on the organism rather than on the activities of microorganisms. This is contrary to the procedure in many laboratories where the study of microbiology tends to stress the processes of microorganisms, and in the opinion of the reviewer, will handicap the book for adoption as a text in many laboratories.

The sequence of presentation of material is in many instances quite different from that of most texts; e. g., the principal discussions of the classification of bacteria and the structure of the bacterial cell are placed at the end of the book. Five chapters at the beginning are devoted to discussions of the history, apparatus, and methods of microbiology, and a general presentation of microbial activities. One chapter each is devoted to the carbon and nitrogen cycles. The sulfur, iron and other oxidizing bacteria are treated in another chapter. Four chapters are devoted to a discussion of the molds, and five to the yeasts. The bacteria are discussed in fourteen chapters, with a good representation of species. Two chapters are devoted to the destruction of microorganisms by various means. The practical importance of microorganisms to everyday life is treated in five chapters. "The final chapters are an attempt to place before both teacher and student some of the theories, problems, difficulties, and controversies that confront the modern microbiologist." Each chapter is followed by a select list of references, which greatly enhances the value of the book to the advanced student.

The originality of the book, with respect to organization, subject matter, and illustrations, together with the clarity of presentation, makes it definitely worthwhile, not alone to the student, but also to the instructor. It is printed and bound in very good style, with only a few of the typographical and other errors which seem inherent in first editions. As minor criticisms, it is suggested that too large a proportion of the text is set in small type; that a brief presentation, at least, of the system of bacterial nomenclature suggested by the Committee from the Society of American Bacteriologists should have been included; and that an author's index of the references

AGRONOMIC AFFAIRS

REPORT ON SORGHUM CONFERENCE

Agronomists interested in sorghum research are indebted to S. C. Salmon, secretary of the standing committee on grain sorghum improvement for a bound, mimeographed report on the grain sorghum conference held at College Station, Texas, September 9 to 12, 1929, which was attended by about 50 agronomists and other station workers. This is an interesting report of the proceedings of the meeting and of the sorghum research work in progress at the various stations in the southern Great Plains.

NEWS ITEMS

PRESIDENT KELLEY announces the appointment of Waldo Kidder of Montana to the special joint committee of the Society with the International Crop Improvement Association, vice Clyde McKee; of Dr. J. B. Park, Ohio State University, as one of the representatives of the Society on the Council of the A. A. A. S., vice W. H. MacIntire; and of J. R. Stanton, U. S. Dept. of Agriculture, to the Committee on Varietal Standardization and Registration.

DR. PETER PIEKENBROCK, exchange graduate student in Agronomy at the Massachusetts Agricultural College in 1928–29 from the University of Halle, is spending the present school year at the University of Wisconsin. He has been succeeded by Dr. Gustav Rohde, also from Halle.

DR. RICHARD BRADFIELD, formerly Associate Professor of Soils at the University of Missouri, has accepted a Professorship in Soils at the Ohio State University and is now located at Columbus, Ohio.

THE ANNUAL business session of the Iowa Section of the American Society of Agronomy was held on December 12. The following officers were elected for the ensuing year: L. C. Burnett, *President;* H. R. Meldrum, *Vice-President;* and R. H. Walker, *Secretary-Treasurer.*

DR. W. E. LOOMIS, Professor of Plant Physiology at Iowa State College, addressed the Iowa Section January 8 on the subject, "Forces Concerned in the Movement of Water in Plants".

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FIELD TECHNIC FOR DETERMINING COMPARATIVE YIELDS IN WHEAT UNDER DIFFERENT ENVIRONMENTAL CONDITIONS IN CHINA[1]

T. H. SHEN[2]

A number of experimenters have reported results of field technic in wheat investigations, but their conclusions do not agree in all cases This seems to be due to the different materials and methods used and to different conditions of soil and weather. It would be of interest to make a field technic study with the same materials and methods under different environmental conditions. With this purpose in mind, the writer presents here the results of his study on competition, the number and field arrangement of replications, and the size of plat at Nanking for the years 1925 to 1928 and at Kaifeng for 1926 to 1928.

Nanking is situated in the southeastern part of China, with a mean winter temperature of 4° C and a minimum temperature of —10° C. The soil is loamy. Kaifeng is located in North China with a mean winter temperature of 0° C and a minimum temperature of —12° C. The soil is a loess with alkaline spots. The two places present a wide difference in mean precipitation, as shown by the following averages for the period of 1906-25:

	Spring	Summer	Autumn	Winter
Nanking.	300 mm	500 mm	200 mm	120 mm
Kaifeng.	100 mm	400 mm	100 mm	20 mm

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[1] Contribution from the Agronomy Department of the University of Nanking, Nanking, China. Received for publication July 15, 1929.

[2] Assistant Professor in Plant Breeding. The author wishes to acknowledge the assistance of members of the Agronomy Department in making calculations reported in this paper.

REVIEW OF LITERATURE

Hayes and Arny (1)[3] used three-row plats of small grain. The rows were 18 feet long and 1 foot apart. At harvest 1 foot was discarded from each end of each row, thus leaving 16-foot rows. Wheat, barley, and oats were tested. The work in 1915 was of a preliminary nature and that in 1916 was used for extensive study. For the study of competition the yield of border rows of the same variety were compared in relation to the height and yield of adjacent rows. A negative coefficient of correlation indicated the effect of competition upon yield or height, while a positive coefficient showed the effect of soil heterogeneity. There was indication of a greater competitive effect between adjacent rows of oats than of wheat. Some effect on the yield of border rows of the same variety due to the height of adjacent rows was found in barley, winter wheat, and one of the two oats tests, but not in spring wheat. The effects of the height of adjacent rows were often sufficient to cause differences of 4 or 5 bushels per acre in the yield of border rows of the same variety of barley. The competitive effect was further evidenced by greater variability in the yield of border rows than of the central rows.

The check plats of oats, spring and winter wheat, and barley were used for a study of the value of replications in reducing error. In nearly all tests three replications as compared with a single plat reduced the error by 25 to 50%. It was concluded that, in general, three or four replications seem to be about as accurate a method as the use of any number below nine.

Love (6) conducted certain experiments at Ithaca, N. Y., where the rows, running north and south, were also 16 feet long and 1 foot apart. He concluded that there was so little competition between varieties usually tested in any one locality that no correction would be necessary, but that it might be well to follow the plan of arranging varieties so that they grade into one another as regards yield, earliness, and the like.

Kiesselbach (3) compared two varieties of winter wheat in both alternating single-row and in alternating 5-row plats sown at the rate of 5 pecks per acre. The rows were 16 feet long and 10 inches apart. He found significant competition and the relative competitive qualities of two varieties reverse in different seasons. He concluded that any crop tested should be surrounded by a crop of its own kind in order to avoid the effect of competition with a dissimilar crop for moisture, nutrients, and possibly light.

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[3] Reference by number is to "Literature Cited," p. 214.

Stadler (8) conducted wheat tests in blocks consisting of five rows, 10 inches apart and 18 feet long, by discarding a foot at each end of each row at harvesting. The rows ran both south and north and east and west. Competition was determined by comparing the relative yields on a percentage basis in interior rows and in border rows of each variety. He found that competition was commonly involved in variety tests, and that it was less when the varieties and strains were structurally similar than when they were widely different. The early, high-yielding varieties profited in competition.

The standard-deviation in single rows was 10% more than in the three-row plats. The five-row and the three-row plats were about equally variable. In replication of plats he found a steady increase in variability as the size of the experimental field was increased. He used percentages instead of actual yields for comparison and this tended to exaggerate his differences.

Summerby (10) conducted blank tests of Welcome oats at Ithaca, N. Y. The probable error of a single observation in percentage was used to measure the effect of different methods. He concluded (a) that small plats were more accurate than large plats, (b) that there was a steady and rapid increase in accuracy as the number of replications was increased, (c) that the most rapid increase in accuracy occurred up to four, (d) that with eight replications there was little difference in the degree of accuracy between the different sizes of plats, and (e) that it seemed likely that the probable error could not be reduced with certainty to less than 2%, even when as many as 16 replications were made.

Stringfield (9) conducted tests with wheat and oats in plats consisting of three rows. The rows were 1 foot apart and 1 or 3 rods long. Three methods were used to measure competition, *viz.*, (a) by using contiguous plats, the difference between the yield of center-row being subtracted from the difference between the yield of adjacent border-row; (b) by a comparison of standard deviations of center and border rows in three-row check plats; and (c) by correlating competition with relative yielding performance, time of maturity, and height. Only occasional indications of yield disturbance from competition were found. Direction of rows did not measurably affect competition. He concluded that if varieties generally similar in growth and in time of maturity were grouped, there would seem to be little competition in the type of nursery plantings studied at Wooster, Ohio.

METHOD AND MATERIALS USED

In the present study, the writer has made use of data of variety tests and has taken the 3-rod-row plat as a unit for each variety or check. The plats were 48 square feet in area with three rows each 16 feet long and 1 foot apart. The rows ran north and south. The check variety occupied every third plat. Every variety was replicated nine times. Each row was harvested separately. No. 26, a selection from the native wheat in the vicinity of Nanking, was used as a check at Nanking. Kaifeng No. 1, an adapted strain of Kaifeng, was used as a check there. Twenty varieties, consisting of native selections and a few foreign varieties, were tested in 1925–26, and 10 more varieties were added in 1926–28 at Nanking. The same varieties tested at Nanking were used in the tests at Kaifeng in 1926–28. In arranging these tests, check plat 1 was sown first, the plat of variety A next, followed by the plat of variety B, then check plat 2, followed in turn by plats of varieties C and D. This plan was continued until each strain was included, thus completing a series. Then the series was replicated nine times. Thus each strain tested was grown next to the check, and every variety appeared in each series. The planting plan is shown below.

Planting plan of wheat tests at Nanking and Kaifeng, showing arrangement of checks and varieties and method of replication.

Variety	Row No.									
	Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Ser. 6	Ser. 7	Ser. 8	Ser. 9	Ser. 10
Check No. 1	1	28	55	82	109	136	163	190	217	244
Check No. 1	2	29	56	83	110	137	164	191	218	245
Check No. 1	3	30	57	84	111	138	165	192	219	246
Variety A	4	31	58	85	112	139	166	193	220	247
Variety A	5	32	59	86	113	140	167	194	221	248
Variety A	6	33	60	87	114	141	168	195	222	249
Variety B	7	34	61	88	115	142	169	196	223	250
Variety B	8	35	62	89	116	143	170	197	224	251
Variety B	9	36	63	90	117	144	171	198	225	252
Check No. 2	10	37	64	91	118	145	172	199	226	253
Check No. 2	11	38	65	92	119	146	173	200	227	254
Check No. 2	12	39	66	93	120	147	174	201	228	255
Variety C	13	40	67	94	121	148	175	202	229	256
Variety C	14	41	68	95	122	149	176	203	230	257
Variety C	15	42	69	96	123	150	177	204	231	258
Variety D	16	43	70	97	124	151	178	205	232	259
Variety D	17	44	71	98	125	152	179	206	233	260
Variety D	18	45	72	99	126	153	180	207	234	261
Check No. 3	19	46	73	100	127	154	181	208	235	262
Check No. 3	20	47	74	101	128	155	182	209	236	263
Check No. 3	21	48	75	102	129	156	183	210	237	264
Variety E	22	49	76	103	130	157	184	211	238	265
Variety E	23	50	77	104	131	158	185	312	239	266
Variety E	24	51	78	105	132	159	186	313	240	267
Variety F	25	52	79	106	133	160	187	314	241	268
Variety F	26	53	80	107	134	161	188	315	342	269
Variety F	27	54	81	108	135	162	189	316	343	270

COMPETITION BETWEEN VARIETIES

NANKING EXPERIMENTS

For the measurement of competition in growth between varieties, the data were treated biometrically in three ways. In the first method, 10 check plats and 10 variety plats which were adjacent to each other were taken as a group. The difference in yield between the central row and one of the border rows of a variety plat was subtracted from the difference in yield between the central row and one of the border rows of the adjacent check plat. When a variety was adjacent to the third row of the check plat, the yield of the third row was subtracted from that of the second row to give the difference in yield in the check plat The yield of the first row of the adjacent variety was subtracted from that of the central row of that plat to give the yield difference of the plat of that variety. With Student's method for comparison, the yield difference in each check plat was paired with that of the adjacent variety plat and subtracted from the latter. Ten pairs were taken together as a group. The following plan illustrates the method of determining the effect of competition:

Check, yield in bushels per acre Row 2—Row 3 = difference	No. 88, yield in bushels per acre Row 2—Row 1 = difference	d	d²
20.23—22.47 = — 2.24	9.20— 9.89 = — 0.69	— 1.55	2.4025
18.15—19.12 = — 0.97	5.91— 5.00 = 0.91	— 1.88	3.5344
29.81—17.70 = 12.11	9.00—10.10 = — 1.10	13.21	174.5041
31.20—26.06 = 5.14	11.55—11.98 = — 0.43	5.57	31.0249
11.55—21.94 = —10.39	10.22— 9.86 = 0.36	—10.75	115.5625
41.00—29.39 = 11.61	13.65—17.96 = — 4.31	15.92	253.4464
21.93—15.93 = 6.00	10.77— 9.32 = 1.45	4.55	20.7025
16.47—23.12 = — 6.65	9.92— 6.96 = 2.96	— 9.61	92.3521
13.64—16.97 = — 3.33	8.25—10.10 = — 1.85	— 1.48	2.1904
20.92—17.00 = 3.92	6.35— 8.46 = — 2.11	6.03	36.3609
	Average =	2.00	10)732.0807
			73.2081

$$73.2081-2^2=69.2081=8.32$$

$$Z=\frac{2.00}{8.32}=0.24 \quad \text{Odds } 3.19:1$$

The average difference, 2.00 bushels per acre as shown in the above illustration, indicates a slight yield disturbance between the check and the variety but is not statistically significant.

This method was used here chiefly because the same pair of a variety and a check can be formed throughout the three years no matter how the order of varieties in the field arrangement was changed. This method gives the same numerical results as the one used by Stringfield (9). He obtained the difference between the middle rows of the check and the variety and subtracted this difference from the difference obtained between the border rows of the check and the variety. As the middle rows of the check and the variety are not adjacent to each other, there is more chance for soil variation in Stringfield's method than in the writer's. When the yield of a variety is higher than that of a check, the signs of deviation computed by Stringfield's method are the same as those by the writer's method. When the yield of a check is higher than the variety, the signs of deviation by Stringfield's method are opposite to those obtained by the writer's method. We assume that A = yield of the middle row of variety, B = yield of the border row of variety, C = yield of the middle row of check, and D = yield of the border row of check. In Stringfield's method, when the border row of a variety is higher in yield than the check, the formula will be $(B-D)-(A-C)=-A+B+C-D$. In the reverse case the formula will be $(D-B)-(C-A)=A-B-C+D$. In the writer's method the formula is always $(C-D)-(A-B)=-A+B+C-D$. The two methods of computation for the varieties 37 and 86ii, which yielded more and less than the checks, respectively, are compared as follows:

Competition disturbance in variety No. 37 and the check at Nanking, 1926–27.

Stringfield's method			The writer's method		
Row 1 of No. 37—row 3 of check*	Row 2 of No. 37—row 2 of check	d (bushels per acre)	Row 2 of check—row 3 of check	Row 2 of No. 37—row 1 of No. 37	d (bushels per acre)
8.99	14.95	— 5.96	— 1.64	4.32	— 5.96
6.19	— 1.22	7.41	8.36	0.95	7.41
3.51	— 4.03	7.54	2.18	— 5.36	7.54
— 1.73	— 8.39	6.66	3.51	— 3.15	6.66
3.95	— 7.54	11.49	4.84	— 6.65	11.49
4.87	— 3.55	8.42	2.65	— 5.77	8.42
2.23	— 1.38	3.61	4.19	0.58	3.61
— 6.60	—10.41	3.81	— 1.05	— 4.86	3.81
3.52	— 3.29	6.81	2.95	— 3.86	6.81

*As the yield of one border row in a plat of variety No. 37 was lost, only nine pairs were used.

Competition disturbance in variety No. 86ii and the check at Nanking, 1925–26.

Stringfield's method			The writer's method		
Row 3 of check—row 1 of No. 86ii	Row 2 of check—row 2 of No. 86ii	d (bushels per acre)	Row 2 of check—row 3 of check	Row 2 of No. 86ii—row 1 of No. 86ii	d (bushels per acre)
21.54	9.43	12.11	— 5.54	6.57	—12.11
19.95	16.75	3.20	— 2.00	1.20	— 3.20
15.80	3.65	12.15	— 6.15	6.00	—12.15
13.80	8.05	5.75	— 2.10	3.65	— 5.75
17.30	13.90	3.40	— 4.45	— 1.05	— 3.40
19.60	10.25	9.35	— 7.25	2.10	— 9.35
12.68	12.53	0.15	2.17	2.32	— 0.15
17.17	8.66	8.51	— 5.35	3.16	— 8.51
12.43	7.21	5.22	4.40	9.62	— 5.22
13.90	7.37	6.53	— 2.80	3.73	— 6.53

The minus signs in the writer's method indicate either higher yield in the border row of check than its middle row and higher yield in the middle row of variety than its border row, or possibly only one of these two differences. The plus signs indicate the opposite condition. When the border rows of a check yield higher than its middle rows, the signs of the deivations are minus. Such results are likely to be misleading, suggesting that competition between the check and its adjacent variety does occur, thus resulting in a higher yield in the middle rows of the variety than its border rows. However, if one studies the computation in details, such confusion will be avoided. But the difference mentioned between the two causes can not be directly seen in the computation by Stringfield's method. The following hypothetical case illustrates the difference between these two methods.

1. *Computation of yield disturbance in the border and middle rows of the variety and the check by the writer's method.*

Check, yield in bushels per acre	Variety A, yield in bushels per acre	d	d^2
Row 2—Row 3 = difference	Row 2—Row 1 = difference		
20.23—22.47 = — 2.24	9.20— 9.20 = 0	— 2.24	5.0176
18.15—19.12 = — 0.97	5.91— 5.91 = 0	— 0.97	0.9409
29.81—17 70 = 12.11	9.00— 9.00 = 0	12.11	146.6521
31.20—26.06 = 5.14	10.00—10.00 = 0	5.14	26.4196
11.55—21.94 = —10.39	8.00— 8.00 = 0	—10.39	107.9521
41.00—29.39 = 11.61	9.00— 9.00 = 0	11.61	134.7921
21.93—15.93 = 6.00	10.00—10.00 = 0	6.00	36.0000
16.47—23.12 = — 6.65	9 50— 9.50 = 0	— 6.65	44.2225
13.64—16.97 = — 3.33	8.90— 8.90 = 0	— 3.33	11.0889
20.92—17.00 = 3.92	9.50— 9.50 = 0	3.92	15.3664
		38.78	10)528.4522
		—23.58	52.8452
		15.20	M = 1.52

$$\text{Standard deviations}-\sqrt{52.8452-1.52^2}=$$

$$\sqrt{52.8452-2.3104}=$$

$$\sqrt{50.5348}=7.11$$

$$Z=\frac{1.52}{7.11}=0.21 \quad \text{Odds } 2.55:1$$

Computation 1 shows that there were differences in yield between the border and middle rows of variety A more directly than does computation 2. The results obtained by the first method at Nanking are presented in Table 1.

A few groups showed significant competition in one year but not in other years. Out of the 26 varieties tested only No. 86hh showed significant disturbance due to competition throughout the three years and Nos. 86ii and 37 in two of the three years. Nos.

2. *Competition of yield disturbance in the border and middle rows of the variety and the check by Stringfield's method.*

Row 3 of check—row 1 of variety A d'_1	Row 2 of check—row 2 of variety A d'_2	d	d^2
22.47 — 9.20 = 13.27	20.23 — 9.20 = 11.03	2.24	5.0176
19.12 — 5.91 = 13.21	18.15 — 5.91 = 12.24	0.97	0.9409
17.70 — 9.00 = 8.70	29.81 — 9.00 = 20.81	—12.11	146.6521
26.06 — 10.00 = 16.06	31.20 — 10.00 = 21.20	— 5.14	26.4196
21.94 — 8.00 = 13.94	11.55 — 8.00 = 3.55	10.39	107.9521
29.39 — 9.00 = 20.39	41.00 — 9.00 = 32.00	—11.61	134.7921
15.93 — 10.00 = 5.93	21.93 — 10.00 = 11.93	— 6.00	36.0000
23.12 — 9.50 = 13.62	16.47 — 9.50 = 6.97	6.65	44.2225
16.97 — 8.90 = 8.07	13.64 — 8.90 = 4.74	3.33	11.0889
17.00 — 9.50 = 7.50	20.92 — 9.50 = 11.42	— 3.92	15.3664
		23.58	10)528.4522
		—38.78	52.8452
		—15.20	
	M =	- 1.52	

$$\text{S. D.} = \sqrt{52.8452 - 1.52^2} = \sqrt{52.8452 - 2.3104} = \sqrt{50.5348} = 7.11$$

$$Z = \frac{1.52}{7.11} = 0.21 \quad \text{Odds } 2.55:1$$

37 and 86hh were taller, stooled more, and headed a little later than the check. No. 86ii, which is a Poulard type, was taller, stooled more, headed 10 days later, and yielded 9.2 to 12.5 bushels per acre less than the check. The difference in these characters between the varieties tested and the check seems to have caused competition.

As the competition was in general not appreciable and as the average yield of the three rows in each plat showed less variation than the yield of single rows, the average yield of 10 three-row plats was taken as representative of the yield. In 1925-28 the difference in yields between the varieties and the check was correlated with the yield disturbance The coefficient of the correlation is —0.442±.073 which is more than six times its probable error. This correlation is certainly significant. It means that the high-yielding variety is benefited in the competition with the low-yielding variety.

The second method of measuring competition was tried, i.e., to compare rows 1, 2, and 3 with the average of all three rows by Student's method. Some varieties and checks which showed significant disturbance through competition and some which did not do so in Table 1 were taken as representative and were tested by this method. As the order of the varieties in the field arrangement was different in 1927-28 from the previous years, the varieties adjacent to the check were also different and the results of this method in 1927-28 can not be directly compared with those in the previous years.

TABLE 1.—*Results of yield disturbance from competition between adjacent three-row plats in wheat nurseries, Nanking data, 1925–28.**

	1925–26*			1926–27*			1927–28*		
Varieties compared	Difference between 3-row average of variety and check in bushels per acre	Difference obtained by method 1 in bushels per acre	Odds	Difference between 3-row average of variety and check in bushels per acre	Difference obtained by method 1 in bushels per acre	Odds	Difference between 3-row average of variety and check in bushels per acre	Difference obtained by method 1 in bushels per acre	Odds
Ck.—8c	—1.3	—2.50	13.6:1	—2.1	1.11	2.55:1	0	1.46	2.97:1
Ck.—26				—0.3	3.73	13.60:1			
Ck.—37	0.2	3.16	18:1	0.5	5.53	344:1	0.6	3.77	100:1
Ck.—86t	—0.3	2.60	3.19:1	—0.3	5.77	22.5:1	3.9	—0.75	<1.59:1
Ck.—86v	0.6	—0.49	2.00:1	—0.4	—1.29	2.97:1	0.2	—3.41	4.11:1
Ck.—54	—1.2	0.30	1.59:1	—0.7	2.36	8.34:1	—1.6	2.49	6.67:1
Ck.—54d				—4.3	0.08	<1.50:1	0.6	—4.86	216:1
Ck.—57a				0.8	0.62	<1.59:1	—1.2	3.92	10.9:1
Ck.—76				4.8	1.53	4.11:1			
Ck.—78a				1.9	—1.69	2.55:1			
Ck.—80				1.3	1.38	2:1			
Ck.—86	3.6	—1.30	2.55:1	8.5	—3.87	18.0:1	3.4	3.00	100:1
Ck.—86ee	1.5	2.66	6.67:1	2.8	—0.08	<1:1	1.2	5.06	29.8:1
Ck.—86ff	0.8	—4.40	13.6:1	—1.8	3.24	10.9:1	—0.2	1.86	8.34:1
Ck.—86gg	2.6	5.58	81.0:1	0.5	0.38	<1.59:1	0.7	4.25	18:1
Ck.—86hh	3.4	2.37	61.1:1	0.3	5.22	344:1	—0.9	5.31	100:1
Ck.—86ii	12.5	—6.64	4999:1	11.1	—1.70	3.19:1	9.2	—8.67	9999:1
Ck.—87				0.8	5.18	10.9:1			
Ck.—88				11.6	2.00	3.19:1			
Ck.—88c	0.3	4.96	262:1	—1.3	4.11	7.24:1	3.0	—1.39	6.67:1
Ck.—3230				1.5	—0.99	1.92:1	5.2	—1.46	5.13:1
Ck.—71				2.7	1.36	2:1			
Ck.—3231				5.3	1.60	3.19:1	5.9	—0.71	2.00:1
Ck.—3232				3.0	4.62	81.0:1	5.3	1.84	4.11:1
Ck.—3233				4.9	1.43	1.92:1			
Ck.—3234				—2.1	4.78	100:1			
Ck.—3235				3.2	3.22	18:1			

1925–26: Total 37.23 regardless of sign

$$\text{Av.}\ \frac{37.23}{12} = 3.103$$

1926–27: Total 65.14 regardless of sign

$$\text{Av.}\ \frac{65.14}{26} = 2.505$$

1927–28: Total 54.21 regardless of sign

$$\text{Av.}\ \frac{54.21}{17} = 3.189$$

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*Column two in each crop year gives the results obtained by method 1 which is that of subtracting differences of center rows minus border rows of variety from differences of center rows minus border rows of check.

TABLE 2.—*Comparison by Student's method of rows 1, 2, and 3 with the average of all three rows at Nanking.*

Variety	Average of all three rows minus the first row			Average of all three rows minus the second row		Average of all three rows minus the third row		
	The first row adjacent to	Average of all three rows minus the first row in bushels per acre	Odds	Average of all three rows minus the second row in bushels per acre	Odds	The third row adjacent to	Average of all three rows minus the third row in bushels per acre	Odds
37								
1925–26	Ck. 2	—0.89	8.34:1	0.89	5.13:1	86t	—0.03	1.59:1
1926–27	Ck. 2	—2.16	216:1	0.51	4.11:1	86t	1.58	100:1
1927–28	Ck. 2	—1.21	61:1	0.92	13.6:1	54	0.31	2.55:1
Ck. 2								
1925–26	26	—0.08	1.59:1	0.44	2.55:1	37	1.84	29.8:1
1926–27	26	1.10	4.11:1	—1.82	81:1	37	—0.79	3.75:1
1927–28	26	—0.08	1.59:1	—0.85	4.11:1	37	0.90	10.9:1
86hh								
1925–26	86gg	0.24	1.59:1	0.92	18:1	Ck. 9	—1.20	18.0:1
1926–27	86gg	1.92	17.9:1	0.27	1.59:1	Ck. 9	—2.01	416:1
1927–28	Ck. 8	0.97	8.34:1	2.82	908:1	86ii	—3.80	344:1
Ck. 9								
1925–26	86hh	0.96	8.34:1	1.01	22.5:1	86ii	—1.97	4.93:1
1926–27	86hh	1.88	1110:1	—0.89	6.67:1	86ii	—1.05	6.67:1
1927–28	86ii	—2.35	29.8:1	1.45	18.0:1	86t	—0.90	4.11:1
86ii								
1925–26	Ck. 9	1.94	163:1	—1.79	416:1	87	—0.32	2.55:1
1926–27	Ck. 9	0.69	5.13:1	—1.62	132:1	87	1.67	37.2:1
1927–28	86hh	3.25	49.3:1	—2.81	22.5:1	Ck. 9	—0.43	2.00:1
Ck. 5								
1925–26	57a	0.22	1.59:1	0.46	2.00:1	76	—1.77	13.6:1
1926–27	57a	—0.43	2:1	—1.51	29.8:1	76	1.88	100:1
1927–28	76	0.49	2:1	1.04	10.9:1	78a	0.51	2.55:1

The results of this treatment as given in Table 2 agree rather well with those of the first method. In some cases the border rows of a variety which were adjacent to the better-yielding varieties yielded more than the middle rows. This may be due to the large vegetative growth of the former variety. The significant difference in yield between the middle row and the average of all three rows is due to yield disturbance of the border rows by being adjacent to another variety.

In the third method, every 10 check plats which were adjacent to the same two varieties in the 10 series were taken as a group in measuring competition in growth between varieties. The yield of the third row in each check plat was paired with the yield of the first row in the same plat The data obtained at Nanking in 1925–28 are presented in Table 3.

TABLE 3.—*Row 1 minus row 3 of check as an expression of yield disturbance from competition between check and adjacent varieties in wheat nurseries, Nanking, 1925–28*

Variety No.*	Check No.	1925–26 Row 1—row 3 of check	Odds	1926–27 Row 1—row 3 of check	Odds	1927–28 Row 1—row 3 of check	Odds
88c 8c	1	—0.67	2.55:1	—4.36	61.1:1	1.28	2.41:1
15b 37	2	4.19	262:1	—0.51	1.55:1	0.97	4.11:1
86t 86v	3	—2.54	10.9:1	—3.22	37.2:1	0.47	1:1
54 54d	4	0.25	1.59:1	—0.26	1.55:1	—4.22	163:1
57a 76	5	—0.99	1.59:1	2.31	10.9:1	—2.50	8.34:1
78a 80	6	—0.26	1:1	3.69	13.6:1	1.92	5.13:1
86 86ee	7	0.29	1.59:1	3.57	61.1:1	1.44	3.19:1
86ff 86gg	8	0.45	1.59:1	1.15	3.19:1	0.96	2.00:1
86hh 86ii	9	—2.93	29.8:1	—2.93	61.1:1	—7.24	132:1
87 88	10	—0.46	2:1	—0.20	1.59:1	—7.61	163:1
88c 3230	11			—5.42	555:1	1.66	9999:1
71 3231	12			0.20	1.55:1	2.18	9999:1
3232 3233	13			—2.47	5.88:1	—1.79	5.13:1
3234 3235	14			—3.18	28.3:1	1.25	2.55:1
3236 3237	15			0.24	1.59:1	—2.24	13.6:1

*In the field arrangement the first row of check 1 was adjacent to variety No. 88c and the third row of check 1 was adjacent to variety No. 8c, and so on for the remainder of the varieties.

Only check 9, which was adjacent to varieties No. 86hh and 86ii, showed significant disturbance in yield from competition two of the three years. This agrees with the result given in Table 1. Check 2, which was adjacent to varieties Nos. 37 and 26, the latter being the same variety as the check, showed significant disturbance from competition with No. 37 only in 1925–26. But according to Table 1, this check lost in competition with No. 37 two of the three years. The significant disturbance in 1926–28, shown in [illegible] 1, is primarily due to the difference in biometrical treatments. The first row of check 2 next to No. 26 should be the same as the second row in showing no competition. Table 3 shows that only the third rows of the check adjacent to the first rows of No. 37 are involved in competition. According to Table 1 both the third rows of check 2 and the first rows of No. 37 are involved in competition, and the sum of the positive difference of check 2 and the negative difference of Number 37 results in significant disturbance from competition in Table 1. This point can be illustrated by Tables 4 and 5.

When check 7, next to varieties Nos. 86 and 86ee, in Table 3, is compared with the pairs of the check with No. 86ee and with No. 86 in Table 1, the results are somewhat different. Table 3 indicates that the competition in check 7 was significant in 1926–27. In Table 1 the yield disturbance between check 7 and No. 86 was very significant in 1927–28. The competition of the check with Nos. 86gg and 88c in 1925–26 and with Nos. 3232 and 3234 in 1926–27 was significant in Table 1 but not in Table 3.

All of these differences indicate that the first method shows greater yield disturbance than the third method. The objection to the third method must be that when two border rows gain or lose in the same direction in competition with adjacent varieties, the significance of competition can hardly be measured.

The difference in yield between the two varieties adjacent to the same check has been correlated with the yield disturbance which is calculated by the third method. The coefficient of such correlation is $-0.415 \pm .088$, a little less than five times its probable error. The difference in yield between the check and its adjacent variety is correlated with the yield disturbance which is calculated by the use of the first method. The coefficient of correlation in this case is $-0.442 \pm .073$. The difference between these coefficients is $0.027 \pm .115$ and is not significant.

TABLE 4.—*The first method of measuring competition between wheat varieties grown in Nanking.*

Check 2: Row 2—row 3 = d_1 in bushels per acre	No. 37: Row 2—row 1 = d_2 in bushels per acre	D (d_1—d_2)
	1925–1926	
20.09—16.05 = 4.04	13.90—19.41 = —5.51	9.55
28.05—20.60 = 7.45	20.60—24.75 = —4.15	11.60
19.20—19.05 = 0.15	18.60—16.55 = 2.05	— 1.90
17.30—15.25 = 2.05	19.20—19.80 = —0.60	2.65
21.85—17.55 = 4.30	21.00—23.30 = —2.30	6.60
26.45—26.55 = —0.10	23.25—25.00 = —1.75	1.65
24.75—25.00 = —0.25	26.40—25.85 = 0.55	—0.80
22.25—30.40 = —8.15	24.35—33.25 = —8.90	0.75
34.95—27.50 = 7.45	39.04—39.63 = —0.59	8.04
30.81—33.82 = —3.01	33.00—29.45 = 3.55	— 6.56
		M = 3.16
	1926–1927	
17.90—19.54 = —1.64	32.85—28.53 = 4.32	— 5.96
23.40—15.04 = 8.36	22.18—21.23 = 0.95	7.41
19.20—17.02 = 2.18	15.17—20.53 = —5.36	7.54
30.39—26.88 = 3.51	22.00—25.15 = —3.15	6.66
39.74—34.90 = 4.84	32.20—38.85 = —6.65	11.49
24.65—22.00 = 2.65	21.10—26.87 = —5.77	8.42
21.88—17.69 = 4.19	20.50—19.92 = 0.58	3.61
32.50—33.55 = —1.05	22.09—26.95 = —4.86	3.81
18.43—15.48 = 2.95	15.14—19.00 = —3.86	6.81
		M = 5.53
	1927–1928	
21.52—19.18 = 2.34	23.13—26.07 = —2.94	5.28
27.76—22.73 = 5.03	20.08—22.70 = —2.62	7.61
28.47—28.77 = —0.30	23.81—25.13 = —1.32	1.02
20.98—25.82 = —4.84	22.81—27.27 = —4.46	— 0.38
27.92—22.96 = 4.96	18.76—23.66 = —4.90	9.86
27.69—29.45 = —1.76	24.00—29.63 = —5.63	3.87
29.97—20.19 = 9.78	27.02—27.00 = 0.02	9.76
21.40—25.30 = —3.90	24.19—26.15 = —1.96	— 1.94
27.70—27.30 = 0.40	25.57—26.05 = —0.48	0.08
32.49—26.78 = 5.71	33.60—30.46 = 3.14	2.57
		M = 3.77

TABLE 5.—*The third method of measuring competition between wheat varieties grown in Nanking.*

Check 2 in bushels per acre

1925–1926			1926–1927			1927–1928		
Row 1	—Row 3	= D	Row 1	—Row 3	= D	Row 1	—Row 3	= D
21.84	16.05	5.79	17.08	19.54	— 2.46	20.68	19.18	1.50
30.34	20.60	9.74	20.15	15.04	5.11	22.10	22.73	—0.63
19.50	19.05	0.45	16.35	17.02	— 0.67	32.07	28.77	3.33
19.30	15.25	4.05	16.40	26.88	—10.48	24.97	25.82	—0.85
26.40	17.55	8.85	34.00	34.90	— 0.90	23.00	22.96	0.04
25.65	26.55	—0.90	24.81	22.00	2.81	23.04	29.45	—6.41
28.10	25.00	3.10	23.13	17.69	5.44	21.70	20.19	1.51
30.08	30.40	—0.32	23.55	33.55	—10.00	28.05	25.30	2.75
36.65	27.50	9.15	21.85	15.48	6.37	32.97	27.30	5.67
36.00	33.82	2.18				29.55	26.78	2.77
		4.21			—0.53			0.97

KAIFENG EXPERIMENTS

Only two years' data are available from Kaifeng. The results of the study there by the first method are presented in Table 6. Not a single group shows significant competition in the two years. In 1926-27 three pairs were significant in competition with the odds over 32:1. The decrease in competition in 1927-28 seems to be due to lack of rainfall in April and May, 1928. The wheat headed in late April and was harvested the latter part of May. On account of this drought, the growth of the wheat plants was checked, the plants failed to utilize the space between them, and the movement of nutrients in the soil was stopped. Thus competition was avoided. The disappearance of competition in wheat due to drought agrees with Livermore's (5) results of a competition study in potatoes.

TABLE 6.—*Results of yield disturbance from competition between adjacent three-row plats in wheat nurseries, Kaifeng data, 1926–28.*

	1926-27*			1927-28*		
Pairing varieties	Difference between three-row average of variety and check (bushels per acre)	Difference obtained by method 1 (bushels per acre)	Odds	Difference between three-row average of variety and check (bushels per acre)	Difference obtained by method 1 (bushels per acre)	Odds
Ck.—8c	— 8.00	—3.20	6.67:1	2.7	—0.77	1.55:1
Ck.—26		—3.88	18.00:1			
Ck.—37	— 9.1	2.93	5.13:1	1.5	—1.10	2.00:1
Ck.—86t	— 4.10	1.87	6.67:1	2.7	0.91	1.83:1
Ck.—86v	— 8.70	—1.69	2.55:1	3.0	0.34	1.00:1
Ck.—54	— 8.90	—2.73	13.60:1	3.4	—4.24	13.60:1
Ck.—54d	— 7.30	0.27	4.11:1	2.7	0.37	22.50:1
Ck.—57a	— 5.70	—4.68	6.67:1	3.2	—0.49	18.00:1
Ck.—76	16.50	—4.37	29.80:1			
Ck.—78a	10.30	—2.65	5.13:1			
Ck.—80	6.20	0.59	2.00:1			
Ck.—86	— 2.50	—5.59	29.80:1	7.0	4.24	10.90:1
Ck.—86ee	—10.70	—3.43	10.90:1	2.1	—2.61	3.19:1
Ck.—86ff	— 8.40	—3.94	8.34:1	4.5	2.16	3.19:1
Ck.—86gg	— 8.30	0.54	2.55:1	1.8	—2.10	4.11:1
Ck.—86hh	— 7.20	—1.19	2.55:1	2.1	—3.58	6.67:1
Ck.—86ii	1.00	—8.38	21.60:1	10.9	4.84	5.13:1
Ck.—87	19.80	—7.37	22.50:1			
Ck.—88	22.10	—4.54	61.10:1			
Ck.—88c	1.80	0.62	1.00:1	3.9	1.33	2.55:1
Ck.—3230	—10.70	—5.31	22.50:1	4.0	—0.78	2.00:1
Ck.—71	6.70	—8.29	344.00:1			
Ck.—3231	2.50	1.06	2.00:1	— 3.2	—3.66	8.34:1
Ck.—3232	— 1.70	—3.72	5.13:1	— 3.6	—3.20	4.11:1
Ck.—3233	10.20	—1.81	3.19:1			
Ck.—3234	4.40	—3.85	18.00:1			
Ck.—3235	10.40	3.18	22.50:1			

1926-27: Total 87.80 regardless of sign

Average $\frac{87.80}{26} = 3.377$

1927-28: Total 36.72 regardless of sign

Average $\frac{36.72}{17} = 2.160$

*Column two in each crop year gives the results obtained by method 1, which is that of subtracting differences of center rows minus border rows of variety from differences of center rows minus border rows of check.

The correlation of varietal difference in yield with the yield disturbance in 1926–28 was calculated. The coefficient of correlation is —0.021±.101 and is not significant. This may have been due to disturbances resulting from the dry spring of 1928, but the coefficient of the correlation in 1926–27, when weather conditions were normal, is —0.112±.131 and also is not significant.

Competition study by the third method is possible only in 1926–27. The results are presented in Table 7. As several varieties were discarded in 1927–28, and since the field arrangement of varieties was different from that in 1926–27, the competition study by the third method in 1927–28 was omitted.

TABLE 7.—*Row 1 minus row 3 of check as an expression of yield disturbance from competition between check and the adjacent varieties in wheat nurseries, Kaifeng, 1926–27.*

Variety No.	Check No.	Row 1—row 3 of check in bushels per acre	Odds
26			
57	2	2.59	29.80:1
86t			
86v	3	0.16	1.00:1
54			
54d	4	0.40	1.59:1
57a			
76	5	—0.44	1.59:1
78a			
80	6	1.23	6.67:1
86			
86u	7	4.37	262.00:1
86ff			
86gg	8	0.66	2.00:1
86hh			
86ii	9	—5.01	555.00:1
87			
88	10	—1.63	5.13:1
593			
3233	11	—0.65	2.00:1
71			
3231	12	4.46	344.00:1
3232			
3230	13	5.83	81.00:1
3234			
3235	14	—0.59	2.00:1

In comparing Tables 6 and 7, cases of similar nature are seen in checks 7, 9, and 12. In Table 7 check 10 was not significant in competition, but in Table 6 the groups of checks with variety No. 88 were significant. These different results between the first and third methods at Kaifeng agree very well with the results at Nanking, and consequently the explanations mentioned above can also be applied here.

COMPARISON OF WHEAT COMPETITION AT NANKING AND AT KAIFENG

By comparing Tables 1 and 6, it is evident that the varieties which showed significant competition with the checks at Nanking did not show significant competition with the checks at Kaifeng, and those that showed significant competition at Kaifeng were not found to show significant competition at Nanking. The yield disturbance between each variety and the check in Table 1 was correlated with the yield disturbance of the same variety with the check in Table 6 and the coefficient of correlation is —0.116±.101 and hence not significant. The difference in yield disturbance is partly due to the different varieties which were used as checks in the two places and in part to the difference in environments. The coefficient of correlation between varietal difference in yield and yield disturbance is —0.442±.073 at Nanking and —0.021±.101 at Kaifeng. It suggests that the causes of competition vary with localities.

The yield disturbance in Tables 1 and 6 were added and averaged by years without regard to their signs because positive and negative signs mean the same from the standpoint of yield disturbance. The averages of the yield disturbance are as follows:

	Nanking	Kaifeng
1925-26	3.103	—
1926-27	2.505	3.377
1927-28	3.189	2.160

The average of yield disturbance at Kaifeng in 1926-27 was higher than that at Nanking. The yields of most varieties were also higher at Kaifeng than at Nanking in 1926-27 as shown in Table 8. The coefficients of variability of yield disturbance in the two places are practically the same. These may be calculated in the following manner:

$$\text{S. D.} = \sqrt{\frac{\Sigma(\text{yield disturbance})^2}{\text{Number of varieties}}} = \sqrt{\frac{245.315800}{26}} = \sqrt{9.435223} = 3.072$$

Nanking.

$$\text{C. V.} = \frac{\text{S. D.}}{\text{average yield of varieties}} \times 100 = \frac{3.072}{21.093} \times 100 = 14.564$$

Nanking.

$$\text{S. D.} = \sqrt{\frac{426.948400}{26}} = \sqrt{16.421092} = 4.052 \text{ Kaifeng.}$$

$$\text{C. V.} = \frac{4.052}{28.544} \times 100 = 14.196 \text{ Kaifeng.}$$

TABLE 8.—*Comparison of wheat yield in bushels per acre in Nanking and Kaifeng for the crop years 1927 and 1928.*

	1926–27		1927–28	
Variety No.	Nanking	Kaifeng	Nanking	Kaifeng
8c	24.4	33.4	27.0	16.2
37	23.0	36.0	25.2	19.1
86t	24.9	31.8	24.2	19.2
86v	25.0	36.4	28.8	17.4
54	24.5	36.3	27.8	17.1
54d	28.1	34.7	25.6	17.8
57a	23.1	37.6	28.2	16.8
76	19.1	15.4		
78a	21.9	19.5		
80	22.5	23.6		
86	16.2	30.1	21.4	13.0
86ee	21.9	38.3	23.0	19.4
86ff	23.6	37.2	24.4	17.0
86gg	21.3	37.1	23.6	18.9
86hh	22.0	35.2	25.2	18.7
86ii	11.2	27.0	18.9	10.0
87	20.0	10.8		
88	9.2	8.5		
88c	23.6	27.0	24.7	17.0
3230	20.8	38.4	21.9	15.1
71	21.3	22.5		
3231	18.7	26.7	21.2	21.5
3232	19.6	29.4	21.2	21.9
3233	17.7	18.6		
3234	23.7	24.1		
3235	18.4	18.1		
15b	23.8	37.0	26.2	16.5
Total	569.5	770.7	438.5	312.6
Average	21.093	28.544	24.361	17.367

DISCUSSION

Competition between varieties depends upon space, rate of seeding, yield, habit of growth, local conditions, and seasonal variations. Myers (7) enlarged the space to reduce competition between apical and basal hills in potatoes. Kiesselbach (2, 4) reported that thin stand lost in competition with thick stand of the same variety of wheat. The present investigation has shown that the yield has a significant correlation with competition at Nanking. Some varieties which are different in yield, height, stooling, or earliness of maturity showed significant competition either at Nanking or at Kaifeng. Some varieties showed significant competition with No. 26 at Nanking but not with Kaifeng No. 1 at Kaifeng, and *vice versa*. The yield disturbance at Nanking did not show significant correlation with that at Kaifeng. Some varieties at Nanking showed significant competition one year but not in other years. In other words, the competition between some varieties can be affected by seasonal variation as well as by local conditions. But there were a few varieties in which the competition occurred every season at Nanking. However, under abnormal weather conditions, such as the spring of 1928 at Kaifeng, not a pair of varieties showed significant disturbance because the full growth of plant was then checked, the space could not be fully utilized, and the movement of nutrients in the soil was stopped. As long as the moisture was sufficient and other conditions were suitable for full growth of plants, competition took place regardless of the difference between the amount of rainfall at Nanking and that at Kaifeng. In fact, in 1926–27, three varieties showed competition with the check at Kaifeng, while three different varieties did so at Nanking.

The influence of competition upon the yield in the border rows is made evident by the difference in yield in these rows in variety No. 37 and check 9 which was adjacent to Nos. 86hh and 86ii at Nanking. The average yield of the second rows of the plats of variety No. 37 in 1925–28 was 23.567 bushels per acre, while that of the first row adjacent to the check was 25.700 and that of the third row adjacent to No. 86t, 23.700 bushels. In the plats of check 9, in 1925–28, the second row yielded 25.100 bushels per acre, while the first row, which was adjacent to No. 86hh, yielded 23.100 bushels, and the third row, adjacent to No. 86ii, 27.300 bushels. In these cases it is safe to let the yield of the second row represent the product of the whole plat in comparison with the other varieties. The average yield of the three rows in each plat is in fact only slightly different from the average yield of the second row because frequently one of the border rows gained in competition while the other lost, thus making little difference in the average of the two border rows.

ARRANGEMENT AND NUMBER OF REPLICATIONS

The arrangement and number of replications of check plats were studied in relation to the effect upon yield variability of checks. Two methods were used in making this study, *viz.*, (a) to compare the yield variability in 5, 8, and 10 consecutive check plats, each in three different series; and (b) to compare the yield variability in check plats 1, 4, and 8 in 5, 8, and 10 consecutive series. The probable error of the mean, in percentage, was used to measure the yield variability. The formula used for calculating the probable error of the mean was $E_M = \pm 0.6745\sqrt{\frac{\epsilon d^2}{n(n-1)}}$. For calculating the probable error of the mean in percentage, the formula $E_{M\%} = \frac{E_M}{M} \times 100$ was employed. The results of this study at Nanking in 1925–28 are given in Table 9.

TABLE 9.—*The arrangement and number of replications of three-row plats with wheat No. 26 as check at Nanking, 1925–28.*

	E_M in %					
	5 consecutive plats	5 plats in 5 series	8 consecutive plats	8 plats in 8 series	10 consecutive plats	10 plats in 10 series
1925						
1*	2.77	5.16	2.06	3.75	5.69	3.70
2	9.22	2.80	2.35	8.76	2.24	7.40
3	7.85	8.79	3.64	5.67	2.93	4.44
1926						
1	3.52	6.61	2.42	1.50	2.07	4.68
2	3.53	8.90	1.36	2.17	1.20	5.30
3	3.99	7.74	2.95	2.48	3.45	6.18
1927						
1	2.84	3.63	2.14	3.34	2.62	2.90
2	7.26	3.10	2.20	2.04	1.83	2.52
3	3.04	4.15	2.83	7.38	2.47	3.98
Total	44.02	50.88	21.95	37.09	24.50	41.10
Average	4.89	5.65	2.44	4.12	2.72	4.57

*Numbers 1, 2 and 3 indicate that the check plats used here were taken from three different parts of the field. These were so chosen that they were about the same distance apart.

From Table 9 a conclusion may be drawn that the range of soil variability is greater when large areas are included, and that the use of too few replications also increases the probable error. The probable errors of 8 consecutive plats were consistently smaller than in the other arrangements and were, on the average, slightly smaller than in 10 consecutive plats. For field tests, the 10 consecutive plat plan is preferred because one or two plats may be damaged by accident and also 10 consecutive plats are convenient for averaging.

In case a variety is not adjacent to a check in the yield test, yields of varieties are usually adjusted by the interpolation method between checks. Small probable errors in yields of checks and varieties are desirable. With this study, a new arrangement of replications is suggested to reduce the size of probable errors. For illustration, there are 20 varieties to be tested and a check occupies every fifth plat. According to this new method, a check is first sown, then varieties Nos. 1, 2, 3, 4, followed by check and varieties Nos. 1, 2, 3, and 4. When nine replications are required, varieties Nos. 1, 2, 3, and 4 are first replicated nine times, and then varieties Nos. 5, 6, 7, and 8 are sown and replicated, and so on. This method should be more effective in reducing the size of probable errors when a large number of varieties are tested. However, if the experimental field has great soil variation and if it is desirable to know the behavior of varieties tested in different kinds of soils, this arrangement of replications may not be desirable.

The results from the study of the arrangement and number of replications of check plats at Kaifeng in 1926-28 are given in Table 10.

TABLE 10.—*The arrangement and number of replications of three-row plats with wheat, Kaifeng No. 1 as checks, in Kaifeng, 1926–28.*

E_M in %

	5 consecutive plats	5 plats in 5 series	8 consecutive plats	8 plats in 8 series	10 consecutive plats	10 plats in 10 series
			1926–27			
1*	1.62	3.57	1.13	2.36	0.95	1.99
2	3.27	3.82	2.03	2.89	1.62	2.39
3	2.77	2.24	3.13	1.82	2.59	2.29
			1927–28			
1	3.77	7.46	6.21	5.81	5.11	4.77
2	3.55	8.39	3.86	8.98	5.51	8.74
3	5.26	9.50	5.09	6.07	4.28	6.97
Total	20.24	34.98	21.45	28.03	20.06	27.15
Average	3.413	5.830	3.575	4.672	3.387	4.525

*Numbers 1, 2, and 3 were arranged in the same manner as in Table 9.

The 10 consecutive plats give the smallest probable errors. At Kaifeng the difference due to different arrangements and different numbers of replications is not so great and consistent as at Nanking. In 1927-28 the probable errors were twice or thrice as great as the corresponding ones in 1926-27. These facts suggest that alkali spots in the experimental field have played an important rôle in soil variation. Greater injury due to alkalinity occurred in the dry spring of 1928 than in the spring of 1927. This accounts at least in part for the greater soil variation and consequently greater probable errors in yield in 1927-28. Nevertheless, in spite of the great difference in soils and climates, the data at Kaifeng still support the conclusions on the arrangement and number of replications which have been drawn from the data obtained at Nanking.

SIZE OF PLAT

In the study of the size of plat in relation to plat variability, the probable error in per cent of the mean yield of single rows, the average of the first and third rows in each plat, and the average of all three rows in each plat were computed. Check 5, and varieties Nos. 57a and 86ff at Nanking and Kaifeng, respectively, which did not show significant competition, were chosen as representatives in this computation. The data from Nanking are given in Table 11.

The probable errors of the single rows were not much different among themselves; and the probable errors of the average of the first and third rows were slightly smaller than those of the single rows, while the average of the three rows shows the smallest probable errors of all. This agrees with Stadler's results. If the relative variability of the yield determined by the different sizes of plats

TABLE 11.—*Size of plat at Nanking, 1925–28.*

Row No.	Variety	1925–26 P. E.$_M$ in %	1926–27 P. E.$_M$ in %	1927–28 P. E.$_M$ in %	Average	Average of averages
1	Check 5	9.47	3.12	4.04	5.543	5.093
	57a	6.65	4.23	3.64	4.840	
	86ff	6.04	5.46	3.19	4.897	
2	Check 5	7.84	5.64	2.43	5.303	5.279
	57a	8.00	5.00	2.94	5.313	
	86ff	6.03	5.95	3.68	5.220	
3	Check 5	9.80	6.90	3.33	6.677	5.586
	57a	6.30	5.25	3.44	5.007	
	86ff	4.80	6.29	4.13	5.073	
$\frac{1-3}{2}$	Check 5	8.87	4.70	3.82	5.797	5.053
	57a	6.68	4.25	2.93	4.620	
	86ff	5.36	5.44	3.43	4.743	
$\frac{1-2-3}{3}$	Check 5	8.30	4.88	2.85	5.343	4.777
	57a	7.17	4.23	2.24	4.547	
	86ff	5.49	4.92	2.91	4.440	

is considered as the criterion of experimental accuracy, then the three-row plat is better but still not much different from the single-row plat under conditions at Nanking.

In Table 11 the size of probable errors of three varieties in each case gradually and uniformly decreased from 1925–28. It indicates that soil heterogeniety was decreased by two years' uniform treatment.

The data on the size of plats at Kaifeng are presented in Table 12. The results are practically the same as those at Nanking. The three-row plat also gave the smallest probable errors at Kaifeng. In 1927–28, the probable errors of different sizes were two or three times their corresponding ones in 1926–27. The increase of the size of probable errors resulted from the increase of soil variation which in turn was due to the increase of injury due to alkalinity in the unusually dry spring of 1928.

TABLE 12.—*Size of plat at Kaifeng, 1926–28.*

Row No.	Variety	1926–27 P. E.$_M$ in %	1927–28 P. E.$_M$ in %	Average	Average of averages
1	Check 3	2.90	7.39	5.145	5.512
	57a	2.86	9.59	6.225	
	86ff	3.58	6.75	5.165	
2	Check 3	2.98	4.24	3.610	5.262
	57a	3.90	9.10	6.500	
	86ff	3.27	8.08	5.675	
3	Check 3	2.00	10.21	6.110	5.845
	57a	4.49	9.90	7.195	
	86ff	1.79	6.67	4.230	
$\frac{1-3}{2}$	Check 3	1.81	7.88	4.845	5.073
	57a	3.41	9.49	6.450	
	86ff	2.33	5.52	3.925	
$\frac{1-2-3}{3}$	Check 3	1.68	6.20	3.940	4.575
	57a	3.09	9.20	6.145	
	86ff	2.34	4.94	3.640	

SUMMARY

The investigation reported here was carried out at Nanking and Kaifeng which possess greatly different climatic and soil conditions.

Many varieties did not show significant disturbance from competition. Some behaved differently in competition in the two places and at different seasons. Only a few varieties showed significant competition throughout the three years at Nanking. However, under abnormal weather conditions, such as the unusual dry spring of 1928 at Kaifeng, not a pair of varieties showed significant competition because the full growth of the plant was checked, the space could not be fully utilized, and the movement of nutrients in the soil was stopped. As long as the moisture was sufficient and other conditions were suitable for full growth of plants, competition took place regardless of the difference between the amount of rainfall at Nanking and that at Kaifeng. In fact, in 1926–27, when the season was normal, three varieties showed competition with the check at Kaifeng, while three different varieties did so at Nanking.

The yield of varieties showed significant correlation with competition at Nanking but not at Kaifeng.

The range of soil variability is greater when large areas are included, and the use of too few replications increases the size of the probable error. The 8 or 10 consecutive plat method of field arrangement gave the smallest probable errors. If the experimental field has great soil variation and if it is desirable to know the behavior of varieties tested in different kinds of soils, this arrangement of replications with small probable error may not be desirable.

The three-row plat is only slighuly better than the two-row and single-row plat under conditions prevailing at Nanking and Kaifeng.

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PERENNIAL WEEDS WHICH SPREAD VEGETATIVELY[1]

B. F. KILTZ[2]

These studies include some of the more common weeds which have become serious on agricultural lands because of their creeping underground parts. Two specific phases of the problem were investigated, first, the extent and nature of the root system itself; and second, the extent and nature of the creeping part of the plant from which new plants arise. All weeds were studied in the field under natural conditions Areas which had not been disturbed recently were selected wherever possible.

The method of study was that used extensively by Weaver (17, 18, 19)[3] in the study of native plants and field and garden crops. This method, as used by the writer, consisted of digging a trench through a typical area of weeds to a depth exceeding the roots of the plant under study. An ice pick was used to remove the soil from about the roots embedded in the wall of the trench. As the roots were exposed they were mapped on cross-section paper. The finished map did not represent a complete root system, but merely a section ranging in thickness from 4 to 12 inches, depending on the amount required to obtain a representative cross-section of the root system.

This method is very useful in studying roots as they occur naturally in the field, and at the same time requires a minimum amount of labor and expense. All excavations were made in the eastern half of Nebraska. The soil in most cases is ordinarily described as silt loam, of either loess or alluvial bench land origin, free of hardpan, and quite fertile. The rainfall averages from 25 to 30 inches a year.

A survey of bulletins, circulars, and other publications describing weeds shows that there is a tendency to use the term "rootstock" to describe all creeping vegetative parts. "Rootstocks" or "rhizomes" are structurally stems developing new shoots beneath the soil. Investigations show that many, if not most, of our most serious weed pests spread by organs which, from all appearances, are structurally roots instead of stems.

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[3] Reference by number is to "Literature Cited," p. 233.

Warming (16) has classified underground "runners" with considerable care. He has arranged plants of this sort according to the type of runner they possess and their position in respect to the soil. He has described the following seven groups. 1, Stolons, or creeping stems above the ground; 2, subsoles, consisting of long slender underground runners which develop aerial shoots; 3, tubers; 4, true rhizomes with short thick internodes from which aerial shoots proceed; 5, rhizodes, long slender runners similar to subsoles but branching at the nodes as do rhizomes; 6, leaf-bearing rhizomes and subsoles without intermediate shoots, and 7, pseudorhizomes, or the surviving bases of the main aerial shoots and their branches which bear winter buds, which may or may not become migratory. Each of these seven groups represent plants spreading by means of stems.

Korsmo (11) has classified runners into (a) long, spreading stems above ground (stolons); (b) underground stems identified by their nodes (rhizomes) which are subdivided into various groups according to their branching and their position in the soil; and (c) genuine runners or true roots.

Pammel and Fogel (13) have studied the creeping parts of some common perennial weeds and have listed those spreading by roots and those spreading by rhizomes as determined by their anatomical structure in microscopic cross-sections of the creeping parts. Those found to spread by roots were Canada thistle (*Cirsium arvense*), pasture thistle (*C. canescens*), horse nettle (*Solanum carolinene*), milkweed (*Asclepias syriaca*), and field bindweed (*Convolvulus arvensis*). Those found to be spreading by rhizomes were common morning glory or hedge bindweed (*Convolvulus sepium*) and quack grass (*Agropyron repens*).

Hitchcock and Clothier (8) have grouped perennial weeds into those reproducing from creeping roots, from vertical roots, from creeping stems, and from a crown, as determined by their external appearances, such as nodes and leaf scales. Among those spreading by creeping roots, they have listed perennial ragweed (*Ambrosia psilostachya*), pasture thistle (*Cirsium undulatum*), Indian hemp (*Apocynum* sp.), milkweed (*Asclepias syriaca*), bindweed (*Convolvulus arvensis*), and sheep sorrel (*Rumex acetosella*). Among those reproducing from vertical roots are horse nettle (*Solanum carolinense*) and ground cherry (*Phyalis* sp.). Among those spreading by creeping stems are wild rose (*Rosa arkansana*), hedge bindweed (*Convolvulus sepium*), perennial smartweed (*Polygonum muhlenbergii*), nettle (*Urtica gracilis*), and wild artichoke (*Helianthus tuberosa*). Among those which form a crown are dandelion (*Tar-*

axium officinale), iron weed (*Vernonia Baldwinii*), and plantain (*Plantago Rugellii*).

Cunningham (7) has listed those spreading by roots to be milkweed, field bindweed, sheep sorrel, Indian hemp, perennial ragweed, and pasture thistle. Those spreading by rhizomes he found to be quack grass, hedge bindweed, perennial smartweed, and wild rose. He also cites a table prepared by Pammel which lists the maximum depth of various root systems of Iowa weeds in which quack grass penetrates 8 inches, horse nettle 36 inches, and milkweed 48 inches.

Rogers, *et al.* (14) describes three important weeds of Colorado, including field bindweed and the two poverty weeds (*Franseria tomentosa* and *Iva axillaris*) as spreading by true roots.

No effort was made in this study to distinguish between various types of rhizomes and of creeping roots. The method used in determining the identity of a root or a rhizome was as follows: 1. Examination for the presence of leaf scales and nodes, especially on the younger growth. Roots do not have nodes or leaf scales. Old rhizomes sometimes lack them, but young shoots can be identified quite readily. 2. The ultimate direction of the tip. A creeping root frequently turns downward to become a feeding root. A rhizome either retains its horizontal position or turns upward to become an aerial shoot 3. Microscopic sections were made in a few instances. The radial arrangement of the fibrovascular bundles in a root contrasts quite clearly with the bundle arrangement of a typical dicotyledon stem in which the vascular system is formed into a closed ring. The creeping parts of monocotyledons (grasses) were, insofar as observed, spreading by scaly jointed stems.

The fact is recognized that the extent of a root system and its arrangement in the soil varies a great deal under different degrees of soil moisture, soil texture, climate, water table, etc. Cannon (5), in working with desert plants, has shown that root systems respond quite definitely to variations in soil aeration. Vorbeb (15) has shown that root penetration is dependent upon soil texture which is responsible for differences in moisture and aeration. Weaver (18) has made studies on the roots of many native and crop plants and has found that climatic conditions have a profound influence upon root development. Cates and Spillman (4), in studies of the rhizomes of Johnson grass, conclude that the compactness of the soil plays a very important part in rhizome development. The root systems as excavated in this study were found to vary tremendously under various soil and climatic conditions, but it is felt that the ones illustrated represent quite typical examples of each species.

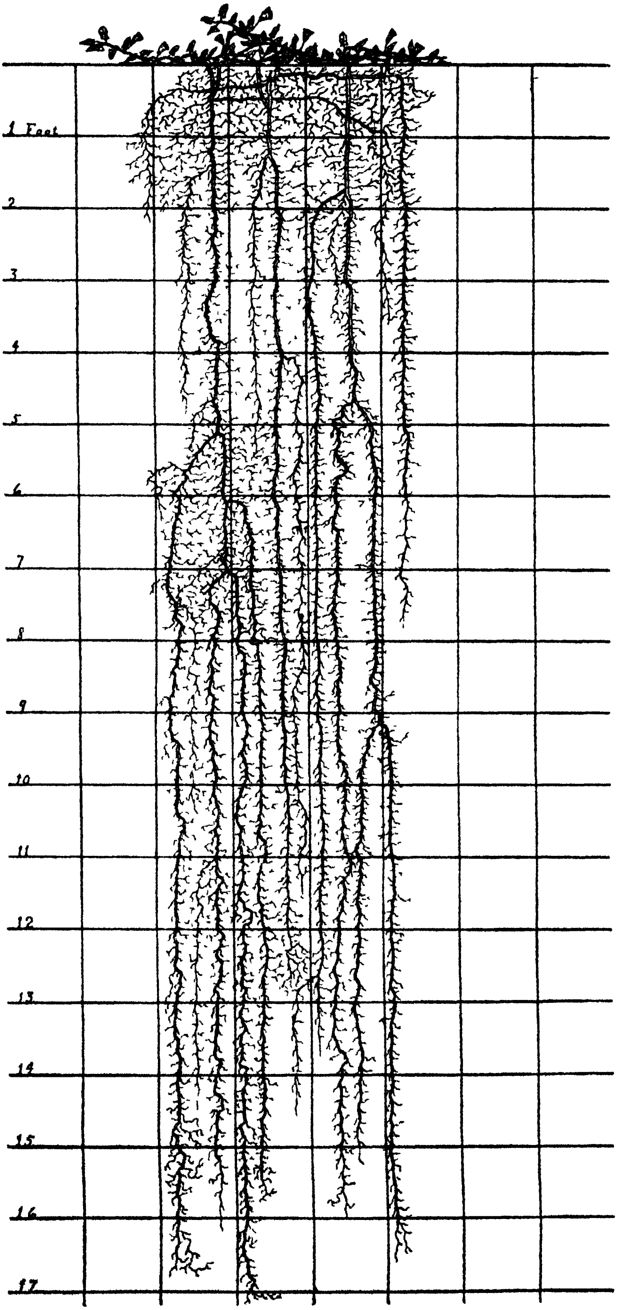

FIG. 1.—Field bindweed (*Convolvulus arvensis* L.)

FIELD BINDWEED

The field bindweed (*Convolvulus arvensis* L.) has become one of the most persistent weeds of cultivated land. Kennedy (10), working under California conditions, reports some plants that retained their vitality after all top growth had been kept down continuously for two and three years. He also found in one instance 300 shoots arising from one root below the point from which the top had been previously cut away.

Bioletti (3), also working in California, found portions of root taken from 14 feet in depth producing new shoots when planted in moist soil.

Rogers, *et al.* (14), working in Colorado, describes the bindweed as penetrating 12 feet to gravel in one study and 16 feet to water in another.

Fig. 1 shows the root system of the field bindweed as excavated at Lincoln, Nebraska. This root system was studied in fertile, bench land, silt loam soil. The surface of the soil had not been disturbed for several years.

The field bindweed spreads by slender creeping roots usually within the upper 4 inches of soil. As this root develops, an aerial shoot, a vertical root, and a lateral branch root are formed. The vertical root develops as a feeding root for the new plant. The lateral root continues as a creeping runner. In cultivated fields and in old, well-established areas of bindweed, these creeping roots are often inconspicuous. Because of their slenderness and their proximity to the surface, they are easily destroyed by cultivating tools and by heavy freezing. New growth after a cultivation is made from the vertical root immediately below the point of injury.

Perpendicular roots are yellow to white in color and range from one-tenth to one-fourth inch in diameter for the first 4 feet. These roots maintained almost a straight course to a depth of over 17 feet. Each cross line in all figures of root systems represents a distance of 1 foot.

HEDGE BINDWEED

Hedge bindweed (*Convolvulus sepium* L.) has not presented the difficulty in eradication as has the field bindweed. This was explained by Irmisch (9) in his descriptions of the two weeds. He described the hedge bindweed as a pseudoannual. The roots of this species die each winter and the plant renews its growth in the spring from the thickened rhizomes.

The root system of the hedge bindweed is shown in Fig. 2. The roots are rather fibrous, brown, and widely branched. These roots

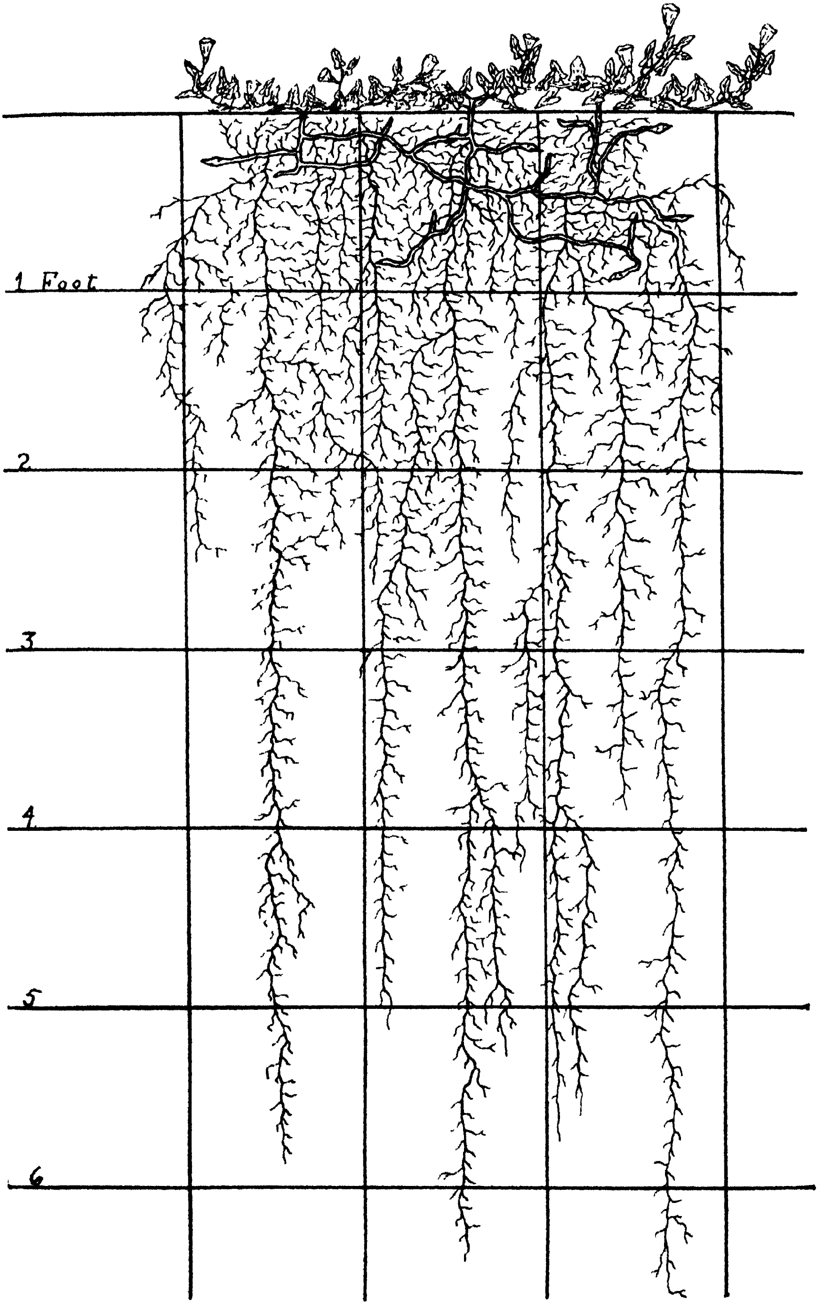

FIG. 2.—Hedge bindweed (*Convolvulus sepium* L.)

penetrated to a depth of 5 to 7 feet in fertile alluvial soil. The plant is propagated by brittle rhizomes. Each rhizome terminated in a thick, fleshy, tuberous tip. New shoots arise from the scaly nodes of these rhizomes. The rhizomes are white to light brown in color and are quite generally distributed through the upper foot of soil.

CANADA THISTLE

Paczosky (12), studying the Canada thistle (*Cirsium arvense* L.) in Russia, found the roots penetrating to a depth of 20 feet. He also noted that a portion of the root system died each winter. Ashlander (2) has taken advantage of this peculiarity by applying various chemicals during the winter months to eradicate the plant.

Arny (1) has described the Canada thistle as penetrating 6 to 7 feet in depth under Minnesota conditions. He also states that pieces of root taken from a depth of 6 to 7 feet produce plants in three weeks.

Canada thistle propagates itself by means of conspicuously white, knotted, fleshy roots. These roots may spread 6 feet or more before bending downward. Numerous adventitious buds are formed along this root to develop into new plants. Aerial shoots developed from roots at a depth of as low as 30 inches. These shoots are true stems and send out slender roots from their nodes.

Vertical roots are similar to the creeping roots and retain their knotted, fleshy condition to a depth of 4 to 6 feet. The maximum root depth as observed on alluvial bench silt loam soils was 8 feet (Fig. 3).

PASTURE THISTLE

Pasture thistle (*Cirsium canescens* Nutt.) is a native plant common in unbroken prairies and in native pastures, sometimes becoming a serious weed when pastures are overgrazed. Hitchcock and Clothier (8) and Cunningham (7) have given *C. undulatum* as the specific name for this plant. Most botanical manuals, however, describe *C. undulatum* as a biennial. Coulter and Nelson (6) have described this thistle under the name *Carduus undulatus canescens*.

Creeping roots spread the plant. The roots are gray or brown in color. Adventitious buds form along the horizontal part to develop new shoots. Vertical roots were found to penetrate to a depth of 6 feet (Fig. 4). This plant was excavated in an overgrazed pasture of glacial loam soil.

COMMON MILKWEED

The milkweed (*Asclepias syriaca* L.) propagates by white or light brown, thickened, fleshy, creeping roots.

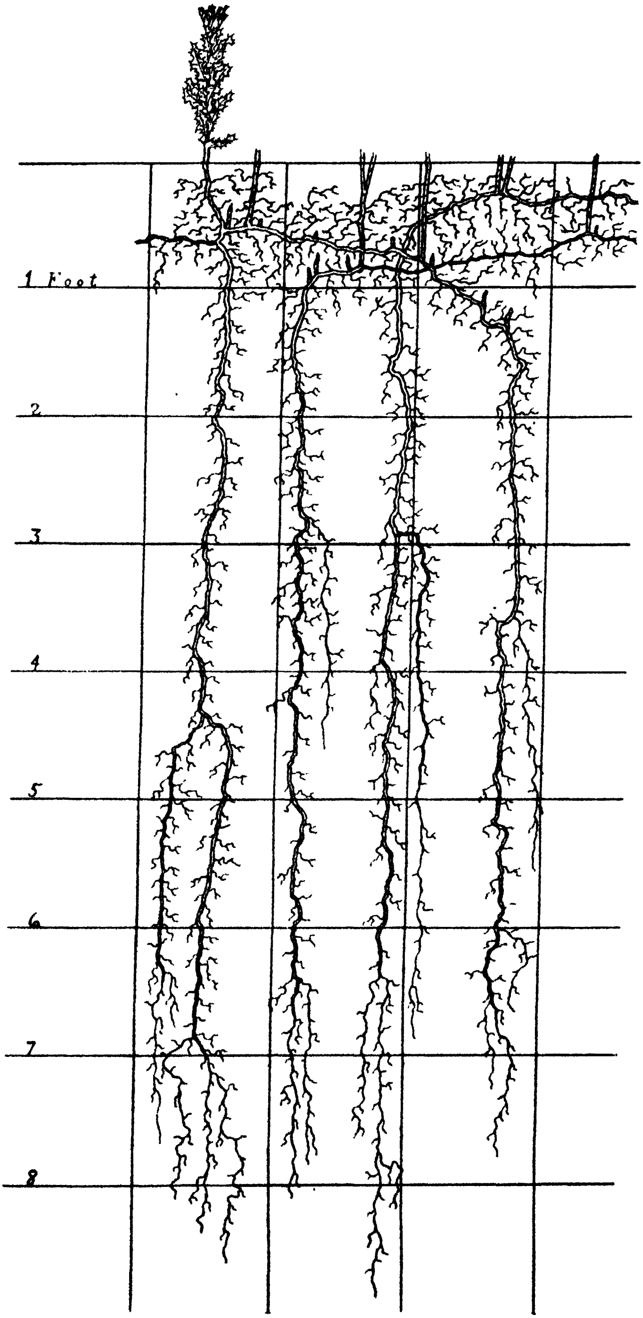

FIG. 3.—Canada thistle (*Cirsium arvense* L.)

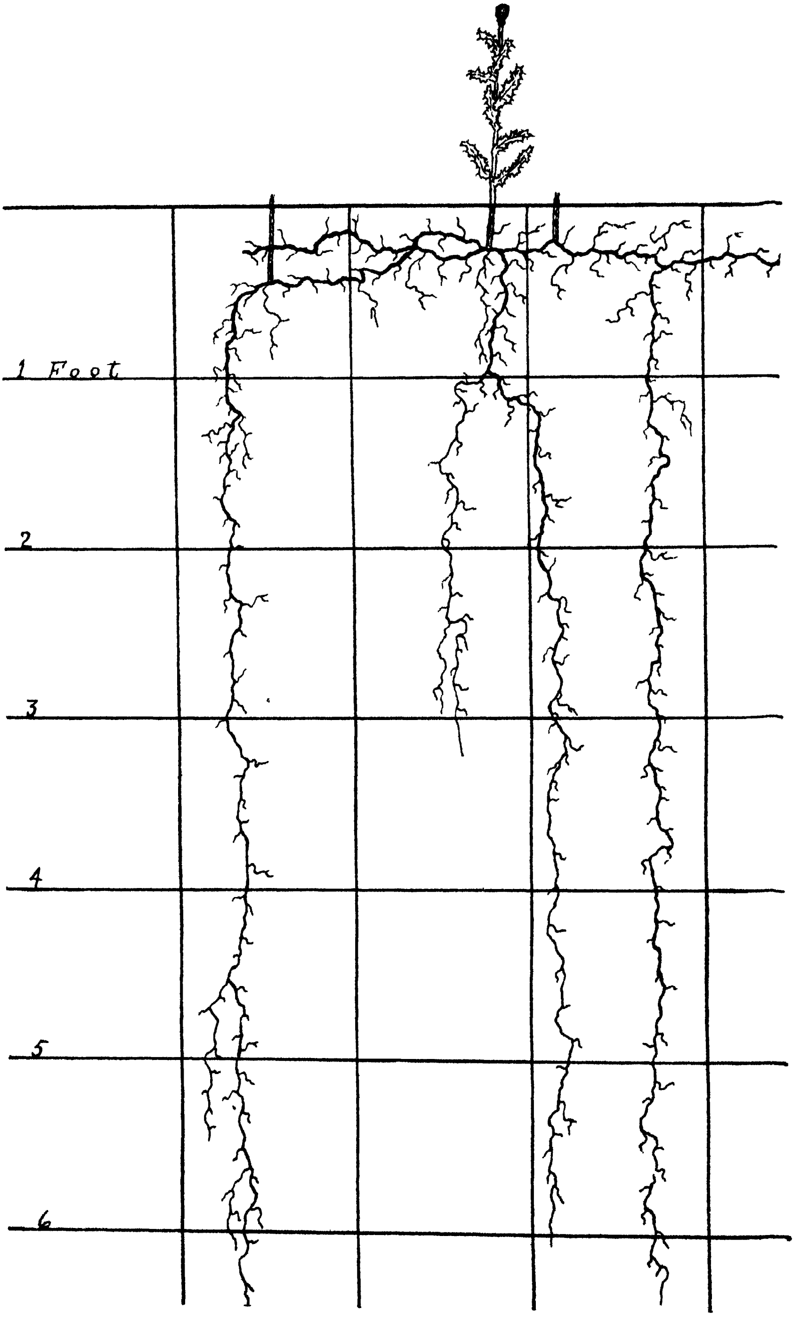

FIG. 4.—Pasture thistle (*Cirsium canescens* Nutt.)

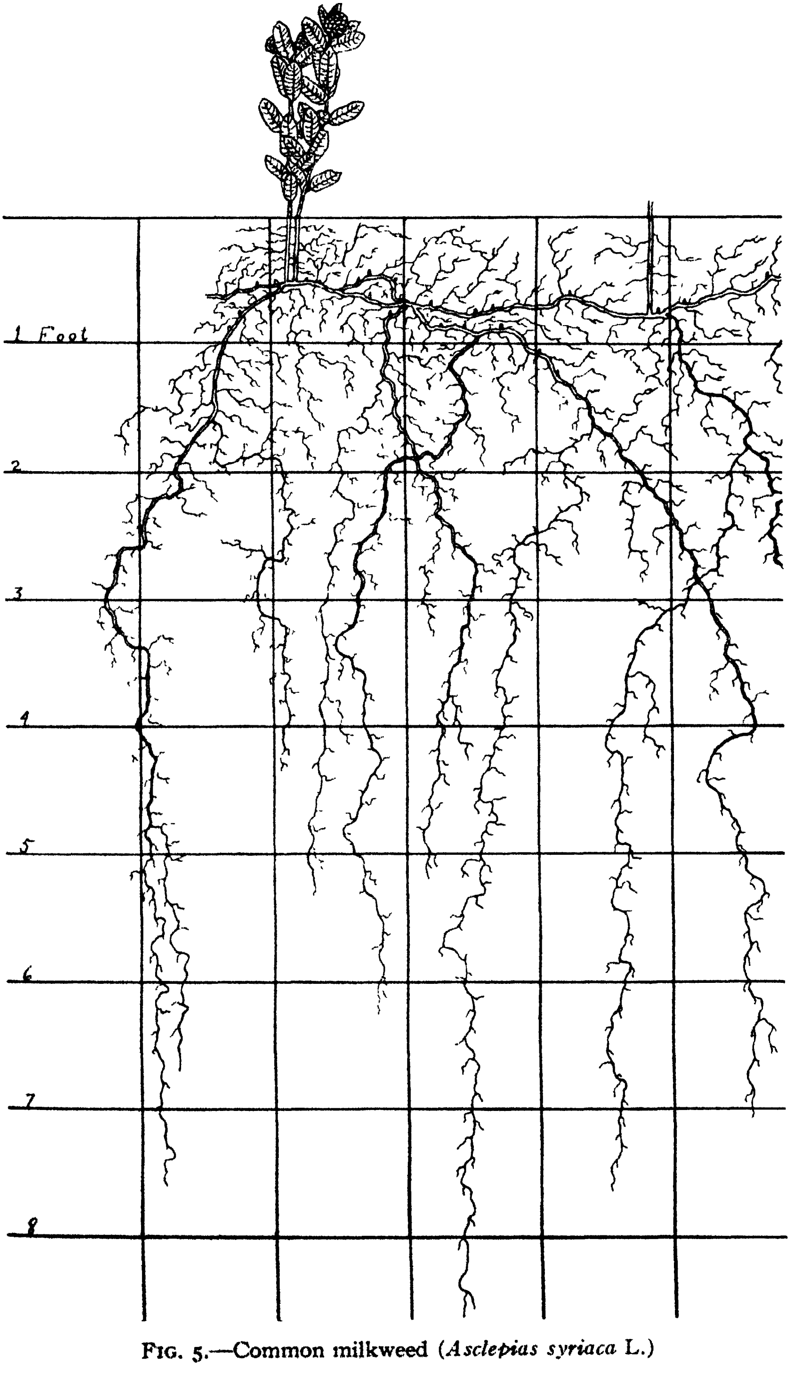

FIG. 5.—Common milkweed (*Asclepias syriaca* L.)

The roots of the milkweed are distributed rather unsystematically through the soil. Most of the main branches of the root system are wide-spread and spread obliquely downward for 3 or 4 feet then assume a more vertical direction to a depth of about 8 feet (Fig. 5). The creeping roots maintain a more or less horizontal course through the upper foot of soil.

INDIAN HEMP

Species of Indian hemp (*Apocynum* sp.) are widely distributed. They become most serious as weed pests in small grain fields and in meadows. The most common species is *A. cannabinum*. The root system of *A. androsaemfolum* has been described by Weaver (18). The roots of the plant (*A. cannabinum* L.) were studied in black loam soil of alluvial origin. Aerial shoots arise from adventitious buds formed on creeping roots. These roots spread extensively and distribute new plants for considerable distances. The roots are thick and white or gray, resembling the milkweed roots described previously. The vertical roots penetrate somewhat irregularly downward to a depth of 5 to 6 feet (Fig. 6).

PERENNIAL SMARTWEED

The perennial smartweed (*Polygonum muhlenbergii*) is found to be most common in low, wet areas, both on cultivated land and in meadows and pastures, although often becoming serious in well-drained land.

Perennial smartweed propagates by long, tough rhizomes, the brown clasping stipules, common to plants of the smartweed group, sheathing each node. Plants often form tangled mats of these well-branched rhizomes. Roots radiate in all directions from each node. Some of these roots become coarse and tough and penetrate to a considerable depth. Others are more fibrous in nature and do not reach far into the soil. The maximum extent of the perennial smartweed roots was not determined. The larger roots were about one-tenth inch in diameter at a depth of 8 feet where excavations were discontinued. Fig. 7 shows the root system of perennial smartweed as excavated on fairly well drained black alluvial soil.

HORSE NETTLE

Horse nettle (*Solanum carolinense* L.) was excavated in heavy alluvial soil. The main roots penetrated almost perpendicularly downward. These roots range from light brown to white in color and are thick and somewhat fleshy. The plant spreads by slender

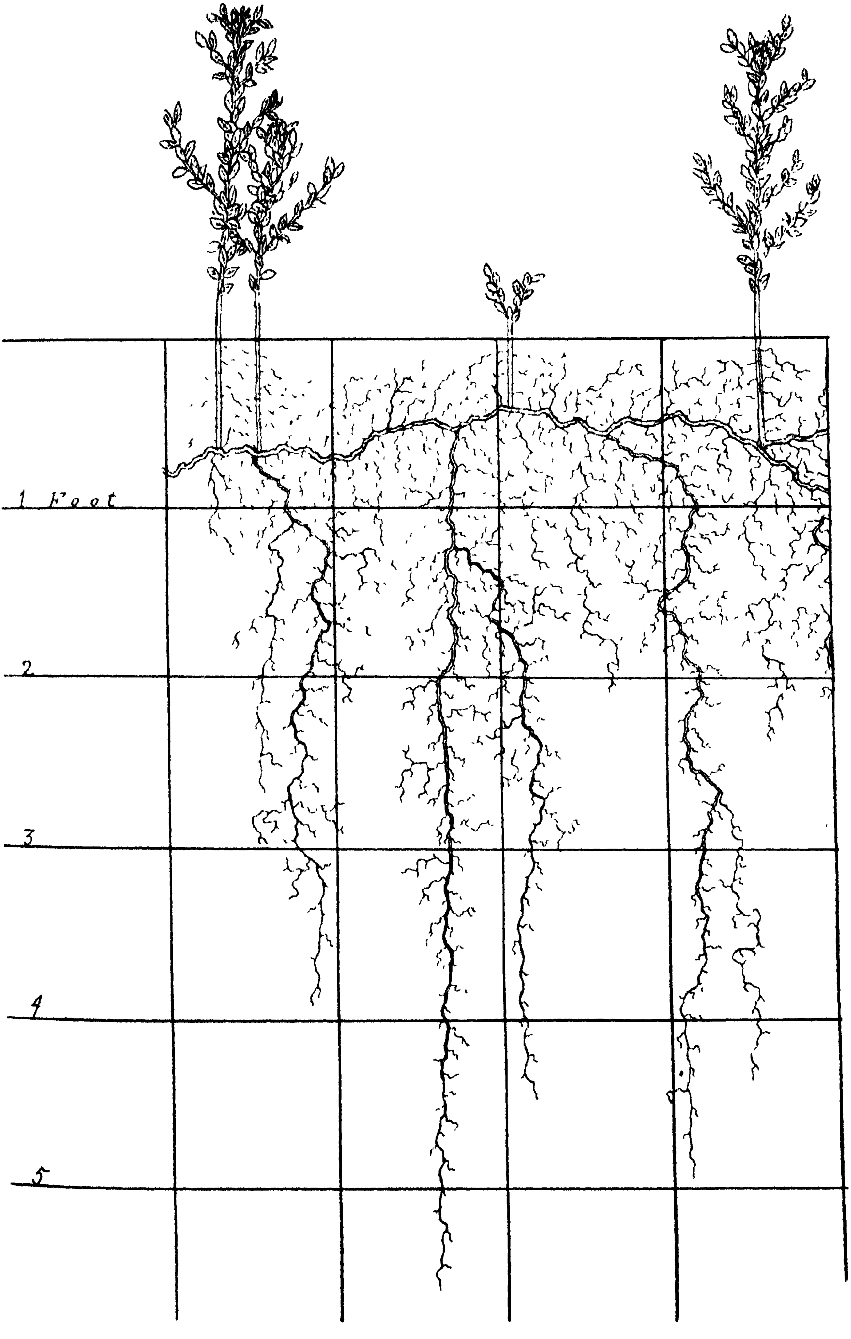

FIG. 6.—Indian hemp (*Apocynum* sp.)

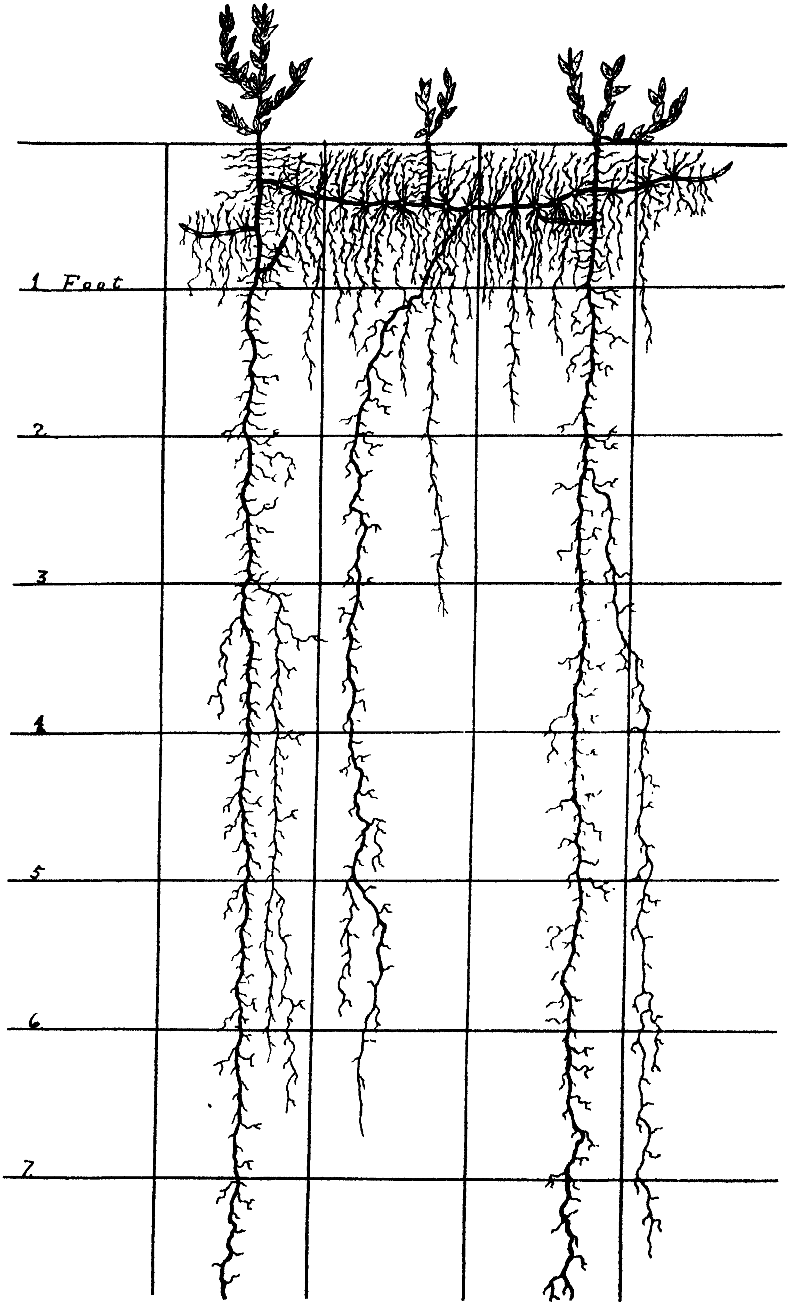

FIG. 7.—Perennial smartweed (*Polygonum muhlenbergii*).

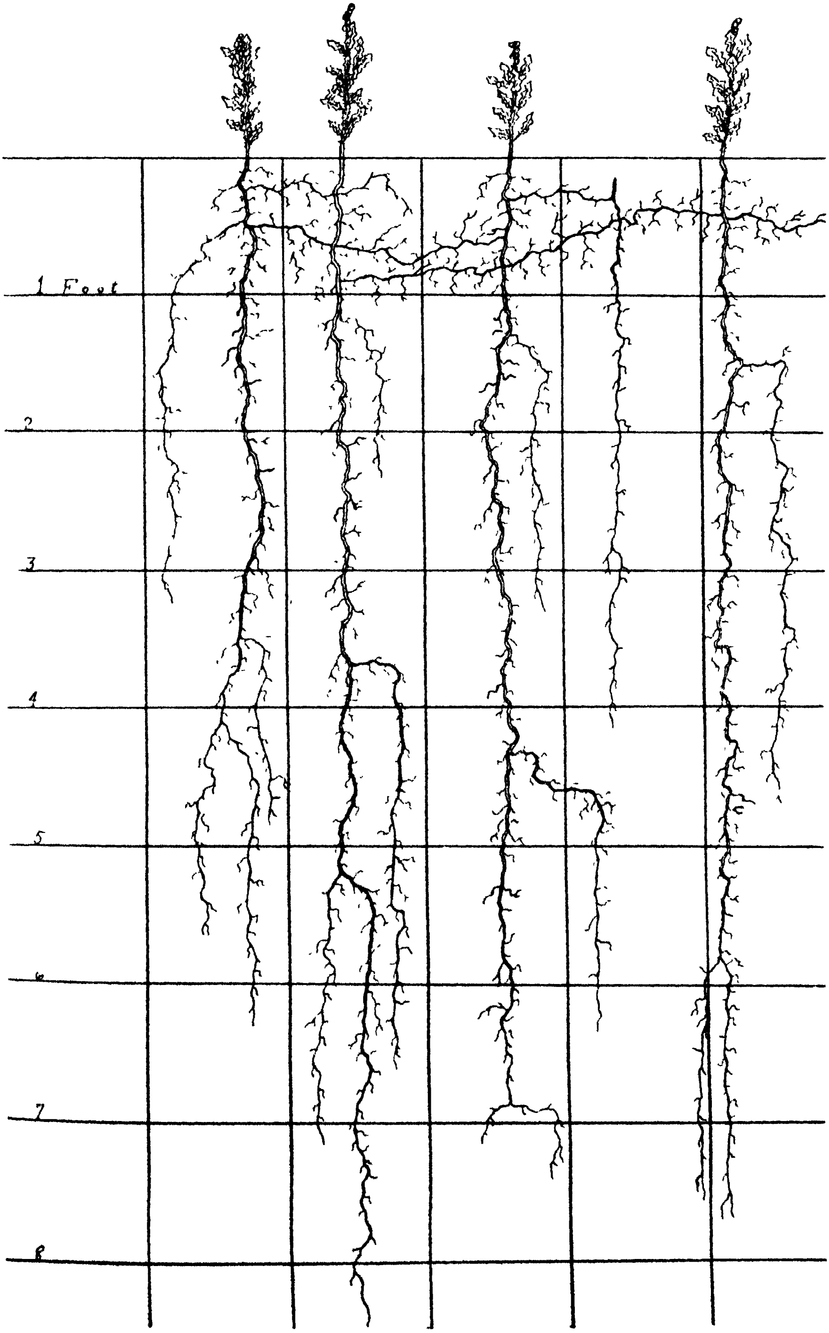

FIG. 8.—Horse nettle (*Solanum carolinense* L.).

creeping roots. Some examinations revealed no creeping roots. Apparently, the plant depends upon seed for distribution as well as upon roots. The horse nettle reseeds itself abundantly by means of small tomato-like fruits.

Vertical roots are prominent and penetrate the soil to a depth of 8 feet (Fig. 8). Creeping roots are found in the upper 18 inches of soil. They extend 3 or 4 feet as a rule, then abruptly turn downward and form new plants. The part turning downward develops into a prominent tap root.

PERENNIAL RAGWEED

Perennial ragweed (*Ambrosia psilostachya* D. C.) is a common weed in pastures, becoming especially troublesome when the pasture is overgrazed. Fig. 9 shows the root system as excavated in a sandy loam pasture.

New plants arise from creeping roots, usually located in the upper 4 inches of soil The feeding roots spread irregularly downward to a depth of 6 feet. Creeping roots were found to be less extensive as a rule in heavy soil, becoming shorter and producing numerous branches.

SHEEP SORREL

Sheep sorrel (*Rumex acetosella* L.) is not ordinarily a serious weed pest in Nebraska, but it occurs frequently in pastures, meadows, and waste places. Some difficulty is experienced at times in eradicating the plant from lawns.

Fig. 10 shows the root system as excavated in a rather low native meadow of loess soil.

The plant propagates by abundant creeping roots found in the upper 8 inches of soil. Numerous adventitious buds form along the root to develop into aerial shoots. These shoots are true stems with brown scale-like leaves below the surface of the soil. Older shoots often develop numerous branches near the surface and take root at the nodes. These, of course, are rhizomes, but this form of vegetative reproduction is relatively unimportant. No leaf scales or nodes are found on the long runners, while numerous leaf scales are found on the short stems developed from the runners. Microscopic examinations also show quite clearly that these two parts are root and rhizome, respectively.

The perpendicular roots are slender, almost fibrous, and extend rather irregularly to a depth of 5 or 6 feet.

A closely related plant, veined dock (*Rumex venosus*), was found to propagate by scaly rhizomes.

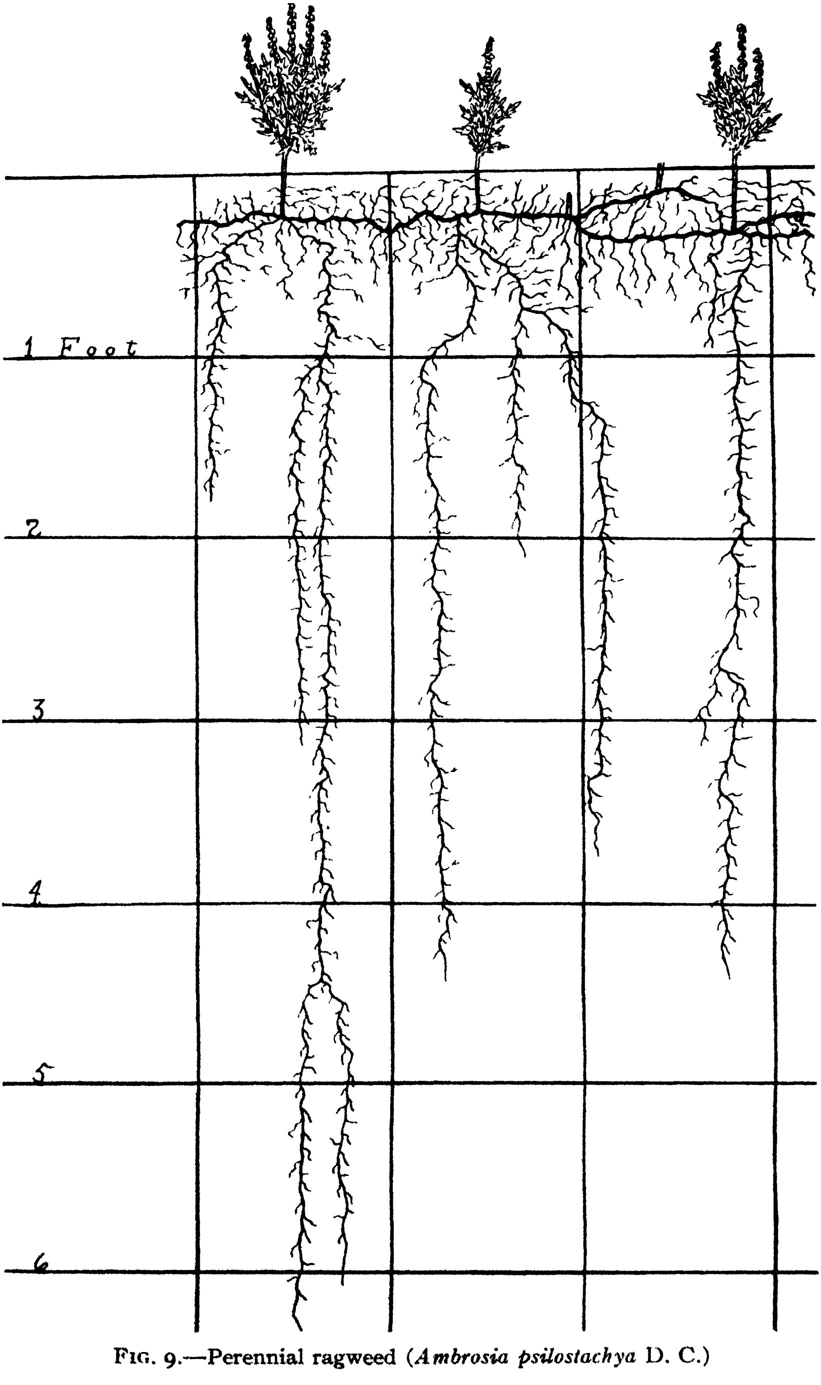

Fig. 9.—Perennial ragweed (*Ambrosia psilostachya* D. C.)

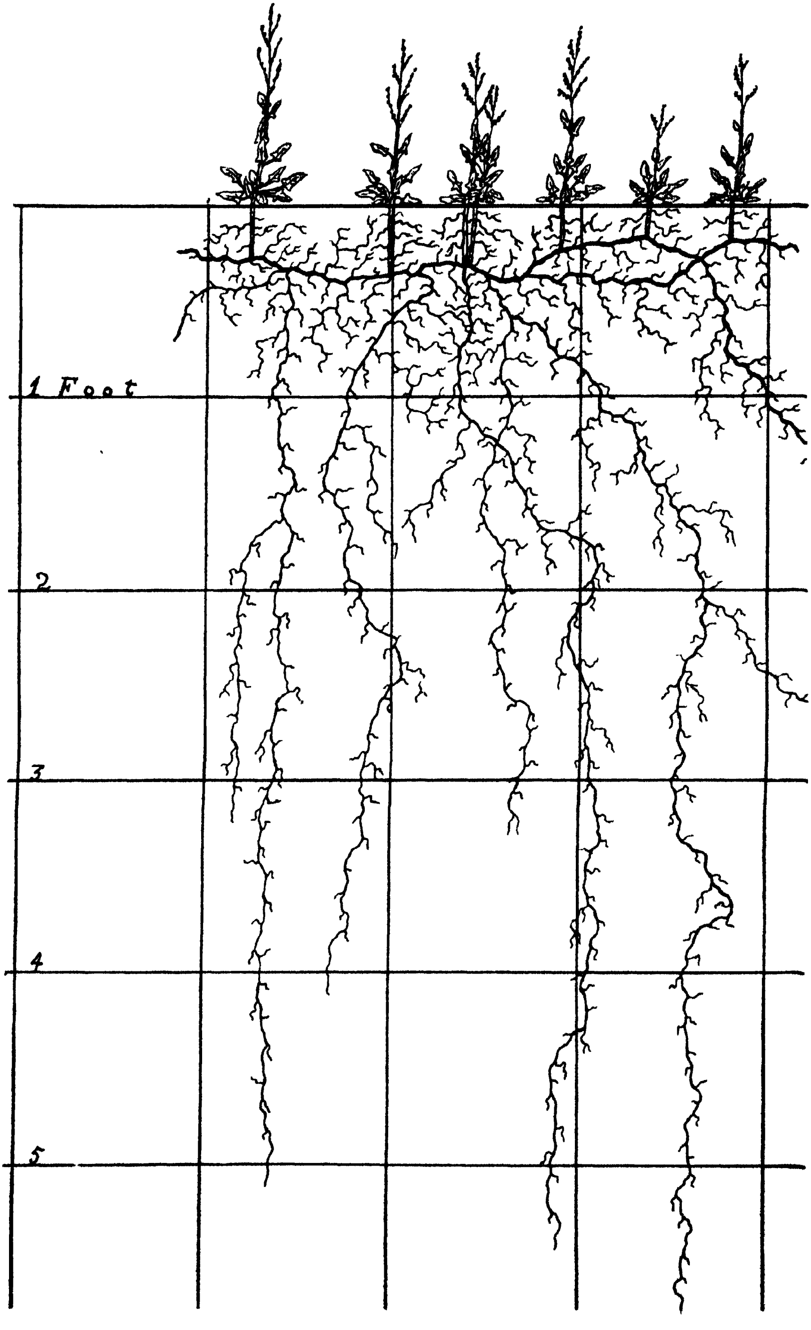

FIG. 10.—Sheep sorrel (*Rumex acetosella* L.)

SUMMARY

The root systems of 10 common perennial weeds which spread vegetatively are described. Eight of the weeds described propagate by roots and two by rhizomes. The results of the findings in this study are briefly summarized in Table 1.

TABLE 1. *Method of vegetative propagation and maximum root depth of 10 common perennial weeds.*

Name of weed	Methods of vegetative propagation	Maximum depth of root system in feet
Field bindweed (*Convolvulus arvensis* L.)	Creeping roots	17
Hedge bindweed (*Convolvulus sepium* L.)	Rhizomes	6
Canada thistle (*Cirsium arvense* L.)	Creeping roots	8
Pasture thistle (*Cirsium canescens* Nutt.)	Creeping roots	6
Perennial smartweed (*Polygonum muhlenbergii* Wats.)	Rhizomes	8 or more
Sheep sorrel (*Rumex acetosella* L.)	Creeping roots and rhizomes	5
Common milkweed (*Asclepias syriaca* L.)	Creeping roots	8
Indian hemp (*Apocynum cannabinum* L.)	Creeping roots	5
Horse nettle (*Solanum carolinense* L.)	Creeping roots	8
Perennial ragweed (*Ambrosia psilostachya* D.C.)	Creeping roots	6

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IS "PEDOLOGY" SOIL SCIENCE?[1]

CHAS F. SHAW[2]

The term "Pedology" is being used by some Europeans and Americans as a designation for soil science, and one Russian journal publishing articles dealing with soil problems has "PEDOLOGY" as its title, as given in English.[3] However, a search of the dictionaries and encyclopaedias of the English language discloses a very different meaning.

Webster's new International Dictionary gives the following:

> "Pedo - Latin - irregular combining form meaning foot.
> Pedo-- paedo-- Greek—combining form --boy, child.
> Pedology (pedo + logy)
> 1. Medical Pediatrics. 2. Child study."

Pediatrics is defined as, "That branch of medical science which treats of the hygiene and diseases of children."

One term with a "soil" meaning was found as follows·

> "Pedograph (Greek-- pedon- ground) an instrument carried by a pedestrian for automatically making a topographic record of ground covered during a journey "

In a "List of new words" included in a late reprinting of this dictionary there is included.

> "Pedology (Gr. πεδον ground + logy) The science which treats of the soil."

No late reprintings of the other dictionaries were available for study, but it may be assumed that this definition will be included in any revised editions.

The new Standard Dictionary gives essentially the same meaning to the words as does Webster's Pedology is defined "(1) same as pediatrics. (2) The study of children " Pedomorphic is "characteristics of youth " Pedometer is ascribed to the Latin root—pes, a foot, and is defined as. "An instrument that measures distances travelled, by recording the number of steps taken by the traveller on whose person it is carried." Pedometer is also defined as "An instrument for measuring the length and weight of children."

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[1] Paper read at the meeting of the American Soil Survey Association held in Chicago, Ill., Nov. 12, 1929. Following the discussion of this paper a resolution was introduced and adopted expressing the opinion that soil science can properly be termed Pedology. This resolution is equivalent to an announcement that the members of the Association intend to use Pedology to indicate Soil Science.

[2] Professor of Soil Technology, University of California, Berkeley, Calif.

[3] Title as given in English on front cover: "PEDOLOGY, Published under the auspices of the Bureau of Representatives of the Pedologists of U. S. S. R. Editor, Prof. Dr. A. Yarilov. Founded in 1899 by P. Otozky."

The Century Dictionary does not include pedology or paedology, but does give several words derived from the Greek—pais or paid = child; pedobaptism—"The baptism of infants," Pedogenesis—"larval generation; reproduction by larvae." It also has Pedometer—"An instrument by which paces are numbered as a person walks . . ."

The Oxford Dictionary gives the same roots and meaning as follows:

> "Paedo—pedo (occasionally paido)—Greek—boy, child."
>
> "Paedology—The study of the nature of children."
>
> "Paedometer—An instrument for measuring the weight and length of a child."

It also has.

> "Pedometer—hybrid, pedo (pedi)—Latin—foot, and metron—Greek—measure or meter. An instrument for recording the number of steps taken. . . ."

The Oxford Dictionary does yield one word, "Pedography," which is of interest to soil scientists and geographers. No definition is given, the note being the only explanation of the meaning, as follows:

> "Pedography (rare)—pedon—ground+graphy. Note: N. Carpenter, 1633—'This description of the dry land separated from the waters we have termed pedography'."

Professor Dr. A. Yarilov, editor of PEDOLOGY, has an excellent discussion on the use of this word in Vol. 22, No. 2, pp 5–11, 1927, of that journal. He credits F Fallou with the first use of "Pedology" to indicate Soil Science, as a title to a 488-page book—"Pedology"—published in 1862. Fallou is quoted as having stated that, "Natural Soil Science or Pedology is a description of the nature of soil, no matter whether it has or has not some bearing to vegetation or to its use for industrial purposes." He used "Agrology" as a knowledge of soil in its relation to vegetation and agricultural use. The term "Pedology" did not come into general use, though Prof. A. Ort was Director of the "Agro-Pedological Institute" of the Agricultural High School in Berlin. Ramann did not use the term, preferring Agrology, and it fell into disuse until taken up again by the Russian soil scientists.

In the meantime the use of the term "Pedology" by those in the field of medicine and public health had established its meaning as given by the dictionaries quoted—the study of the nature of children. In Russia the term is used with this meaning as evidenced by many publications. In 1927, Arymov published in Moscow his "Principles of Pedology," dealing with the growth and development of children. Berestnyva published "A Report of Pedological Surveys on First Grade Pupils." In the September, 1928, issue of the *Journal of Genetic Psychology* on pages 350 and 351 in an article on "Psychology in Russia" by A. R. Luria is the following:

> "The problems of pedology and genetic psychology are occupying a considerable place in the modern psychological literature in Russia. In 1925 appeared the first edition of Professor Blonski's 'Pedology' and in a few months there was a demand for a second edition. . . . The same views are popularly stated in other books of his: 'Pedagogics,' 'Pedology in Public Schools,' and also in the two volumes of the researches of his laboratory at the Academy of Communist Education—'Pedology and the School.'
>
> "A very important place in pedology is occupied by the Leningrad school under the direction of Professor Bassov. Many years ago in St. Petersburg there originated the psychological school of Professor Lazurski's, the aim of which was to combine the positive features of psychological experiment with the natural observation of the child."

Although the dictionaries of the English language seem to indicate that the Greek words paedo, paido, and pedo all mean child or boy, this is not borne out by the Greek lexicons. In these **παιδο** (paido) in various combinations means child, while **πεδο** (pedo) means ground. Liddell and Scott's Greek-English lexicon gives **πέδον** (pedon), **εδἄφος** (edaphos), and **κθονος** (Kthonos) as ground or earth. Other lexicons agree with these meanings and also agree that **παιδός** (paidos) means child or boy. Evidently, the child specialists and men of medicine should designate this work as "Paedology" or "Paidology."

Despite these facts, it seems rather apparent that anyone endeavoring to find out the meaning of the word "Pedology" by study of the usual source references would conclude that it dealt with the science of children, rather than with the science of the soil. Without doubt, Fallou's use of the term establishes priority of use for the soil scientists, but the generally accepted meanings, as evidenced by the dictionaries, have no reference to soil.

Yarilov, in addition to his discussion of "Pedology" in the paper previously referred to, briefly discusses the use of the terms "Edaphology" and "Khtonology" for soil science. "Edaphology" has been suggested by several scientists in Europe and America. In 1910, Ball and Piper suggested its use in their paper, "Technical Terms in Agronomy," in the Proceedings of the American Society of Agronomy, Vol. 2, 1910.

In 1922, Lyon and Buckman designated their book, "The Nature and Properties of Soils" (Macmillan), in a subtitle as "A Textbook of Edaphology."

In 1924, S. Stuchasiev also proposed its use in a paper given at the Soil Conference at Rome (Actes de la IV^{ene} conference internationale de Pedologie, Vol. III, p. 706, Rome 1926), and I have on several occasions advocated the use of "Edaphology" for soil science (American Soil Survey Association, Bulletin 8, pp. 66–97, 1927; Bulletin

9, pp. 23–58, 1928; and International Congress of Soil Science, Vol. 4, pp. 38–54, 1928).

"Edaphology" was used in *Botanical Abstracts* (Vol. 14: 340, 1925) 340, as one of two subdivisions of Agronomy. The first, "Crop Science (arviculture)," appeared on page 327, the second subdivision, "Soil Science (edaphology)," on page 340. This usage has been maintained in *Biological Abstracts* which succeeded *Botanical Abstracts* in 1926.

Webster's new International Dictionary is the only one of those studied that included a word derived from the root, edaphos, as follows:

> "Edaphic. 1. Pertaining to, or affected by the state and condition of the soil rather than by climate (phytogeography). 2. Indigenous: local."

The use of "Edaphology" by Lyon and Buckman is interpreted by Dr. Buckman (personal communication) in the rather restricted sense of "the soil in its relation to plants" rather than with a pure soil science meaning. Their interpretation is essentially like that given by Fallou to the word "Agrology."

The situation with respect to the English language has been briefly set forth A similar condition exists in German, with "Bodenkunde" used for the practical soil knowledge and no term for the science or "wissenschaft " In Russian the term "Pochvovedenie" is derived from the words "Pochva"—soil—and "vedat"—to know - plus the ending "nie" indicating neuter gender. Literally, it is soil knowledge.

No term has come into general use that adequately indicates "Soil Science." Librarians and others who may have occasion to look up the meaning of the word in the current editions of the dictionaries would certainly conclude that "Pedology" referred to the work of child specialists There is ample evidence that by priority in use and in the exact root from which the word is derived, "Pedology" should mean soil science, while "Paedology" could indicate child science. It is quite apparent that in the established usage of the English language "Pedology" *does not now* indicate Soil Science.

BREEDING WHEATS RESISTANT TO BUNT BY THE BACK-CROSS METHOD[1]

FRED N. BRIGGS[2]

The production of agronomically desirable varieties of wheat resistant to bunt, *Tilletia tritici* (Bjerk.) Wint., should be of great value in materially reducing the enormous annual losses due to this disease. The average annual loss of wheat from bunt in the United States for the 10-year period 1918–1927 was approximately 17,000,000 bushels.[3] This is second to an average yearly loss of about 26,000,000 bushels of wheat from stem rust in the same period. Besides the reduction in yield, there is a large loss from dockage owing to the presence of smut, and in the cost of cleaning smutty grain. According to Meier,[4] the dockage at the Kansas City market from July to October, 1926, amounted to $272,210, an average of more than $10 a car. Bunt may be controlled in most regions by the use of fungicides, but the most economical and satisfactory control lies in the use of resistant varieties, which eliminates the expense and inconveniences of treatment, and also takes care of situations where treatment is ineffective.

EXPERIMENTS AT DAVIS, CALIFORNIA

In the spring of 1922, the bunt-resistant variety Martin was crossed with most of the important varieties of wheat grown commercially in California. The plan was to back-cross to the commercial variety until the final progeny should be essentially the same as the commercial parent, with the bunt resistance of Martin. Theoretically, this result should be possible except for factors closely linked with the bunt-resistant factor. Martin was chosen for the resistant parent because it had been completely resistant to bunt in the Pacific Coast states (14)[5] and because the data available indicated that it con-

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[1] Joint contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the California Agricultural Experiment Station, Berkeley, Calif. Received for publication Oct. 2, 1929.

[2] Associate Pathologist, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Associate in Agronomy, California Agricultural Experiment Station. The writer acknowledges valuable suggestions from Dr. R. E. Clausen, Division of Genetics, and various members of the Division of Agronomy, University of California, and members of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3] U. S. D. A., Bur. Plant Indus., Plant Disease Reporter, Supplements 6, 12, 18, 24, 30, 36, 43, 49, 56, and 64. [Mimeographed.] 1919–1928.

[4] MEIER, F. C. Market studies. U. S. D. A., Off. Ext. Work and Bur. Plant Indus., Coop., Ext. Path., 4(1):7–8. [Mimeographed.] 1927.

[5] Reference by number is to "Literature Cited," p. 244.

tained one dominant factor for resistance. Hussar, the only other completely resistant variety available at that time, appeared to have more than one factor for resistance to bunt. Later, the writer (3) showed that Martin has one dominant factor for resistance to bunt and that Hussar has the same factor and probably just one other.

The back-cross project has not been completed, but the results have been so encouraging that it seems worth while to outline the method followed. The status of the project for one of the varieties of wheat, namely Baart, is shown graphically below.

Year	
1922	Martin x Baart
1923	F_1 x Baart
1924	Plants segregated—1 resistant: 1 susceptible
1925	Plants segregated—3 resistant: 1 susceptible
1926	1 homoxygous: 2 heterozygous rows Homozygous resistant plant x Baart
1927	F_1 x Baart

In 1924, the ratio of resistant to susceptible plants was approximately 1:1. There was a slight excess of plants in the resistant group, because some susceptible plants always escape infection. The row progeny from such an escaped plant is classified easily the following year.

In 1924 and 1925, only resistant plants were saved In 1926, about one-third of the rows were homozygous for resistance to bunt, and the rest were segregating for resistance. By classifying the rows as soon as they headed it was possible to cross homozygous resistant Baart-like plants with Baart that same year Baart was crossed with plants in a number of rows which at that time appeared to be most like Baart. Some of these plants later proved to be quite like Baart in all visible characters, while others were not so Baart-like. The latter, together with the resulting hybrids, were discarded. Selection of the desired types at this time will undoubtedly speed up the attainment of the final goal.

In 1930, homozygous resistant rows again will be available. Judging from the results obtained to date, it seems very probable that in 1930 a large number of strains will be essentially Baart, with the resistance of Martin. The time required to compare these strains with Baart before distributing them possibly may be somewhat shorter than is usual with new varieties.

Since so little time and effort is required to carry out the back-cross program during the first few years, it is planned to put all new varieties in the back-cross nursery as soon as it seems likely that they will be suited for commercial growing in California. In the future, it will not be necessary to use a resistant parent as different from the commercial type as Martin. A number of selections of spring wheats which have the Martin factor for resistance will be available. In following this plan, only wheats as resistant as Martin will be introduced into California agriculture by the experiment station

FEASIBILITY OF THE BACK-CROSS PROGRAM

The first duty of the plant breeder interested in breeding smut-resistant varieties of wheat should be to put resistance into the commercial varieties of wheat now grown. In every wheat region there are some varieties which have been grown for many years, and which, in all probability, will continue to be grown for a long time. For example, Sonora wheat probably has been grown in California since the beginning of agriculture, and there is no indication that it will be entirely replaced in the near future

According to Clark (4), Turkey (including Kharkof) and Marquis wheats represented about half the total wheat acreage in the United States in 1924. It is certain that large acreages of these varieties will be grown for some years. If Turkey and Marquis were back-crossed to Martin, substituting the resistant strains for the present commercial ones, it should be possible in time to plant approximately one-half the acreage of the United States to wheat as resistant as Martin. If a similar program were carried out with the eight wheats Arnautka, Big Frame, Fulcaster, Fultz, Kanred, Marquis, Poole, and Trukey, assuming that these varieties would occupy the same acreage as in 1924, approximately 70% of the acreage of theUnited States could be planted to wheat as bunt resistant as Martin. Arnautka might offer some difficulties because it is a durum wheat.

EFFECT OF PHYSIOLOGIC RACES

Physiologic forms of bunt are known to exist. At present comparatively little is known about the number and distribution of the different forms. In 1924, Faris (7) published the first evidence of physiologic forms of bunt. Previously, Faris (6, 8) had discovered physiologic forms of covered smut of barley, and Reed (11) had reported physiologic forms of oat smuts. Rodenhiser and Stakman (13), Gaines (9), and Reed (12) have presented additional data on the physiologic forms of bunt.

Martin has been free from bunt at Davis over a period of 11 years. A similar record was obtained at Moro, Oregon, until 1926, when this variety was first attacked at that station. Gaines (9) obtained 38% of bunt on Martin at Pullman, Wash., in 1927, when it was inoculated with bunt from Germany. As much as 78% of smut was reported on Martin by Roemer at Halle-Saale, Germany (9), in 1927. Since that time Martin has shown varying degrees of susceptibility to bunt collections from various sources, but it has been resistant to many other collections with which it has been tested.

The number of physiologic races of bunt is not known at the present time. Theoretically, new races may arise by mutation or by recombination at any time, although this has not been demonstrated.

Stakman recently stated that 51 forms of stem rust of wheat, *Puccinia graminis tritici*, have been isolated. This would be a staggering number if the plant breeder had to isolate a different resistant factor for each of the 51 forms. Fortunately, the forms may be grouped with reference to certain resistant varieties of wheat so that the number is considerably reduced for practical breeding purposes

Aamodt (1, 2) has shown, for example, that the resistance of Kanred to 11 forms of the stem rust organism is due to a single factor. These 11 forms then may be considered as one by the plant breeder using Kanred as one parent. Khapli emmer, similarly, is resistant to 50 forms. This leaves only one form to be taken care of by another variety when Khapli is used as a parent. Unfortunately, Khapli is an emmer and is not readily available as a resistant parent for breeding resistant bread wheats This situation has been improved, however, by the recent development of Hope, a typical *Vulgare* wheat selected from a cross of Marquis wheat on Yaroslav emmer by E. S. McFadden of Day County, S. Dak. According to Clark and Ausemus (5), its reaction to stem rust is similar to that of the Khapli, Vernal, and Yaroslav varieties of emmer, which usually are rust free, but may carry from 1 to 2% under conditions of maximum infection. They found that resistance was inherited as a dominant character. Varieties showing similar resistance to many or all physiologic forms of the bunt organism, also, may be found or developed.

OTHER BUNT-RESISTANT VARIETIES

Martin was used as the resistant parent in the experiments here reported because it has a single factor for resistance, thereby making the back-cross program a simple one. It seems desirable to continue with Martin for the present. There are other wheats resistant to bunt which may be used as more is learned about the genetics of their resistance. As soon as Faris (6, 7) showed that there are physiologic forms of bunt and of covered smut of barley and Reed (11) reported physiologic forms of oat smuts, the writer began a study of the genetics of resistance to bunt in other known bunt-resistant varieties of wheat. An attempt is being made to determine the number of different factors present and the effect of each. Martin is known to have one dominant factor for resistance to bunt. Hussar has the same factor as Martin and one other Turkey, Florence, White Odessa, Ridit, etc., may have still different ones

As more is known about the number and distribution of physiologic forms of bunt in the United States, and as more is known about the genetics of bunt resistance in the various resistant varieties of wheat the back-cross program may profitably be changed from time to time.

DISTRIBUTION OF BUNT-RESISTANT SEED

A very important consideration in developing bunt-resistant varieties is to keep such seed from becoming mixed with that of susceptible varieties when placed in the hands of the farmer. Even slight admixtures with susceptible varieties might permit enough smut to cause considerable dockage, even though the reduction in yield would be slight Some method of handling this phase of the problem should be worked out In some states existing pure seed associations should be able to handle the situation In any case, a close contact should be effected with extension agencies and a pure seed supply should be insured, since it is poor policy to spend public funds in expensive research, and to lose the result of this research through neglect.

DISCUSSION AND SUMMARY

The value of back-crossing for incorporating and fixing characters undoubtedly has been apparent to all students of genetics. Breeders of animals long have used this method to fix desirable characters. Harlan and Pope (10) apparently are the only ones, however, who have reported the use of back-crossing in plant breeding for the purpose of introducing and fixing a desirable character from one variety into an otherwise desirable variety which lacks it.

Where it is desirable to incorporate several desirable characters in a given variety, it will be necessary usually to set up a separate program for each character and carry the different strains along until incorporation has been effected. Finally, by intercrossing these strains the desired combinations may be obtained. By such a method it would be relatively easy to incorporate in a single variety such factors for resistance to bunt as are available to the plant breeder.

The back-cross method for putting resistance to bunt into the commercial varieties of wheat gives the plant breeder a definite program, the results of which he may predict in advance. As the method is automatic, it can not fail. Moreover, the facilities required and the expense are only a fraction of those necessary with the usual method.

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UNUSUAL CROSSING IN OATS AT ABERDEEN, IDAHO[1]

F. A. Coffman and G. A. Wiebe[2]

PREVIOUS EXPERIMENTS

Several papers dealing with natural crossing in oats have been published in recent years. The climatic conditions under which experiments were conducted, and the varieties used, differed widely, yet the reported results are similar for all.

Stanton and Coffman[3] have published on systematic natural-crossing experiments conducted at Akron, Colo.; Griffee and Hayes[4] on experiments conducted at St. Paul, Minn.; and Garber and Quisenberry[5] on experiments conducted at Morgantown, W. Va. The methods of these three investigations were similar, and similar results were obtained.

The method of determining the amount of natural crossing in all three experiments consisted of sowing dark-colored and light-colored oat varieties which flower simultaneously in adjacent rows, or in rows near one another. The percentage of crosses was determined from the number of heterozygous, dark-kerneled progenies in the rows sown with seed from the rows of the light-kerneled variety. Stanton and Coffman observed 0.05% of crossing in Pringle Progress and 0.97% in Iowar. One strain of Iowar showed 4.32% of crossing. Griffee and Hayes found 0.04% crossing in Victory and 1.47% in Fulghum. They emphasize the necessity of controlling pollination in studies of the frequency or probability of mutation. Garber and Quisenberry observed more crossing between varieties of *Avena byzantina* ♀ x *A. sativa* ♂ than reciprocally, or between varieties of *A. sativa*. In Fulghum they observed 0.91% crossing and state that climatic conditions influence the amount of crossing from year to year.

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Data obtained in cooperation with the Idaho Agricultural Experiment Station. Received for publication October 7, 1929.

[2] Associate Agronomist in Oat Investigations, and Assistant Agronomist, formerly in charge of cereal experiments of the Office of Cereal Crops and Diseases at the Aberdeen (Idaho) Substation, respectively.

[3] Stanton, T. R., and Coffman, F. A. Natural crossing in oats at Akron, Colorado. Jour. Amer. Soc. Agron., 16:646–659. 1924.

[4] Griffee, Fred, and Hayes, H. K. Natural crossing in oats. Jour. Amer. Soc. Agron., 17:545–549. 1925.

[5] Garber, R. J., and Quisenberry, K. S. Natural crossing in oats at Morgantown, West Virginia. Jour. Amer. Soc. Agron., 19:191–196. 1927.

None of these writers present data on the distance to which pollen may be borne by the wind and produce hybrids.

MATERIALS AND METHODS

In 1927, the writers conducted a study of individual oat plants at Aberdeen, Idaho. The plants were spaced at foot intervals in rows 6 feet long and 1 foot apart. The plants were thus spaced 1 foot apart in all directions. The experiment was surrounded by a similarly planted border row of oats. Outside of this border row and 1 foot apart were two additional border rows of Federation wheat sown with a drill. No oats were sown nearer than 20 feet from this experiment. Sufficient seed was not available to sow a 6-plant row of all varieties and hybrids grown in this experiment.

Most varieties used in this study were rather early maturing and short-strawed types, and the variety Richland was chosen to occupy blanks and to sow the guard row surrounding the experiment. The seed of Richland was grown at Aberdeen in 1924.

All plants in this study, including space fillers and border plants along one side of the experiment, were harvested and threshed individually. Plant grain yields were exceptional for many of the space-filler plants of Richland As Richland had not been reselected during the more than 20 years since the original selection was made, it was decided to sow a rod-row of each of the best yielding Richland plants. Sixty-nine plants were grown at Aberdeen, Idaho, in 1928.

RESULTS

When the plants in the rows grown from seed of the individual Richland plants headed and ripened, much heterogeneity was noted. Most of the plants were normal Richland, but a large proportion of the rows contained aberrant plants. Most of the aberrants were dark-kerneled, but others were yellow-kerneled, and five were intermediate-fatua-like types. In Fig. 1 a row containing an unusually large number of aberrants is shown.

As the parent plants of Richland had been harvested and threshed individually, the aberrants were either natural hybrids or mechanical admixtures.

Seeding rates in these rows were light and the plants in each row could be pulled separately and counted. Data are given in Table 1. The percentage of black or brown-kerneled aberrants varied from 0.19 to 6.62%, with an average of 1.28% for all rows containing aberrants.

In order to determine the genetic nature of these black aberrants, progeny rows were grown in the greenhouse at Arlington Experiment

Farm, Rosslyn, Va., in 1928–29. The results obtained were conclusive evidence of their hybrid nature Only small populations could be grown, but in general they segregated in a ratio of three dark-kerneled to one light-kerneled. The two exceptions observed are noted in the data. Progeny numbers necessarily were small, due to lack of space, but the writers believe that all aberrants were hybrids.

The yellow aberrants also are believed to have been natural hybrids, but this could not be proved conclusively, due to lack of a satisfactory differentiating character. The number, maximum, and average of the yellow aberrants are given in Table 1.

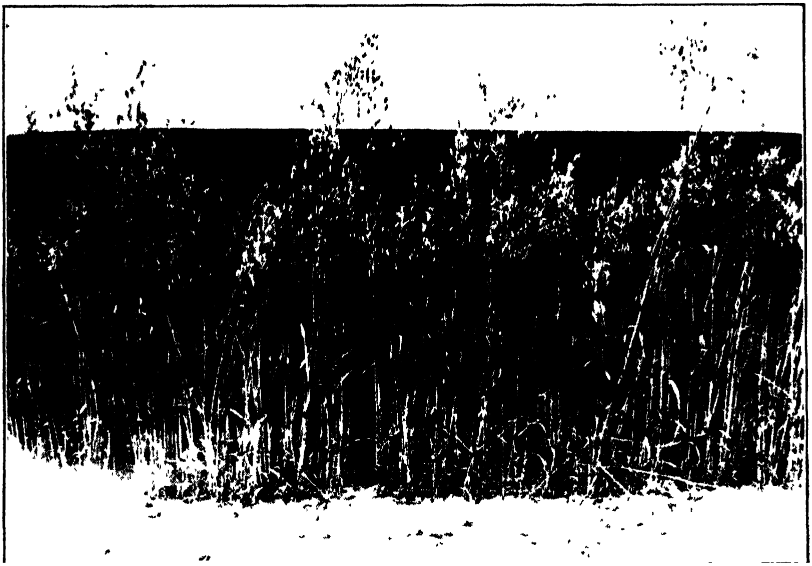

FIG. 1.—A row of Richland oats grown at Aberdeen, Idaho, in 1928, which contained a large number of aberrant plants. These later were shown to be natural hybrids.

Seed of the five intermediate fatua-type plants was sown in the greenhouse, and their progeny gave a segregation of one fatua-like form to three cultivated and intermediate forms. Both fatuoid and *A. fatua* plants were grown in the experiment at Aberdeen in 1927, and there was an opportunity for them to cross with Richland.

Several explanations have been given for the origin of fatuoid or false wild oats in cultivated varieties. The occurrence of natural hybrids between fatuoid or *Avena fatua* plants and cultivated oats is of interest in this connection. Four of these intermediate wild types were produced from seed grown on plants located at a distance of 1

TABLE 1.—*Distance of parent plant to nearest dark-kerneled plant, total number of progeny rows grown, and number and percentage with dark-kerneled aberrants; total plants and number of aberrant plants grown, and average and maximum number and percentage of dark- and light-kerneled aberrants per progeny row of Richland oats grown at Aberdeen, Idaho, in 1928.*

Distance of parent plant to nearest black-kerneled plant in feet	Progeny rows			Plants in the progeny rows which contained aberrants									
	Total number	With dark-kerneled aberrants		Total number	Dark-kerneled aberrants	Dark-kerneled aberrants per row				Light-kerneled aberrants per row			
						Average		Maximum		Average		Maximum	
		No.	%			No.	%	No.	%	No.	%	No.	%
1	27	21	77.8	8,392	159*	7.57	1.89	22	6.62	1.19	0.30	10	3.75
2	9	7	77.8	2,626	19*	2.71	0.72	8	2.47	2.57	0.69	10	3.05
3	9	6	66.7	2,577	22	3.67	0.85	9	3.09	4.00	0.93	13	3.56
4	3	0	0.0	—	—	—	—	—	—	—	—	—	—
5	3	2	66.7	820	9	4.50	1.10	8	2.61	2.50	0.61	3	0.97
6	1	1	100.0	343	2	2.00	0.58	2	0.58	10.00	2.92	10	2.92
7	7	2	28.6	660	3	1.50	0.45	2	0.64	12.50	3.79	18	5.17
8	5	3	60.0	1,343	7	2.33	0.52	3	0.96	4.33	0.97	13	4.17
9	4	4	100.00	1,349	11	3.50	0.82	7	1.99	9.00	2.67	15	4.46
11	1	0	0.0	—	—	—	—	—	—	—	—	—	—
Total, average or mean	69	46	66.67	18,110	232	3.47	0.87	7.63	2.37	5.76	1.61	11.50	3.51

*Including one plant which did not segregate but was believed to be hybrid.

foot, and one from seed grown on a plant at a distance of 8 feet from the nearest fatuoid or *A. fatua* plant. So far as the writers are aware, this is the first case of natural crossing between wild or fatuoid and cultivated oats where the parentage could be traced with a fair degree of certainty.

DISTANCE AT WHICH OATS CROSS NATURALLY

The distance between each Richland parent plant of the progeny rows grown in 1928 and a black-kerneled plant was easily determined.

In numerous experiments conducted by the writers in which oat plants were studied individually, natural crossing has not been observed in such amount previous to this study. The cause of such widespread crossing is difficult to understand Black Mesdag, the black-kerneled variety of which there were the most plants in the 1927 experiment at Aberdeen, usually produces relatively abundant pollen. The heading date of Black Mesdag averaged about five days later than that of Richland

The data on the percentage of crossing in Richland in relation to the distance from the nearest black-kerneled parent plant are presented in Table 1.

At Aberdeen in 1927, the wind carried viable oat pollen to a distance of at least 10 feet. The percentage of crossing should diminish with increase in distance. At a distance of 1 foot 77.8% out of 27 plants showed evidence of crossing. Even at a distance of 9 feet, all four plants tested showed natural crossing. Within these limits there was little decrease in the amount of cross-pollination.

During that part of the season when oats flower and ripen at Aberdeen, the air usually is very warm and dry during the day and relatively cool at night. Rain seldom occurs during this part of the year, and cloudy weather is rare. All crop production is by irrigation. In this section the oat flowers usually open and pollination occurs most abundantly in mid-afternoon between 3:00 and 4:30 p. m. Moderate winds usually occur during the latter part of the day at this season, and whirlwinds or gusts of wind of considerable intensity may be experienced. These conditions are ideal for wind dissemination of pollen, and may account for the distance at which natural crossing in oats occurred in this experiment. The data do not show the extreme distance at which crossing may occur at Aberdeen, since as much occurred at a distance of 9 feet as occurred at 2 feet. The data indicate the importance of natural crossing, particularly to those conducting experiments with cereals in nursery rows and field plats.

SUMMARY

1. Natural crossing occurred in 46 of 69 plants of Richland oats grown at Aberdeen, Idaho, in 1927. The amount of crossing in 46 progeny rows from these plants containing dark-kerneled aberrants varied from 0.19 to 6.62%. The total number of plants in these 46 rows was 18,110, and the number of black aberrants was 232, or 1.28% of the whole. In addition to the 232 dark-kerneled aberrants, 149 yellow-kerneled aberrants were found in the progeny of these plants.
2. It was found that 77.8% of the 27 plants grown 1 foot from the nearest black-kerneled plant bore crossed seed. Crossing took place in all of four plants grown 9 feet from the nearest black-kerneled plant.
3. More crossed florets occurred in plants grown 1 foot from the nearest dark-kerneled plant than in those grown at a greater distance. The maximum distance at which oats will cross is not shown by these results
4. Five natural crosses between *Avena fatua* or fatuoids and the cultivated variety Richland were observed.

THE INFLUENCE OF TOPOGRAPHY ON SOIL PROFILE CHARACTER[1]

E. A. Norton and R. S. Smith[2]

Soil is recognized as a natural body, the character of which is determined by the material from which it has been developed and the environment to which it has been subjected Variations in environment, therefore, give rise to variations in soils, since both the direction and rate of reactions responsible for soil development are controlled by environment (11).[3]

Glinka (1, pages 32 34) expressed the idea, and the view is now generally accepted, that the character of the end-product of soil weathering is a result of environment and that it is affected but little, if at all, by the character of the parent material from which the soil was derived. According to this view, parent material would be excluded as one of the variable factors which influence the character of a mature soil Maturity, as the term is used in this paper, carries a slightly different meaning from that expressed by Shaw (12) in that it denotes a stage of profile development so advanced that future changes under the same environment will be slow. The environmental factors which govern the conditions under which profile development takes place are drainage, slope of the land surface, organic activity, both vegetative and animal, and the various climatic forces.

The purpose of the investigation herein described was to ascertain whether a quantitative relationship exists between slope of the land surface, one of the variable environmental factors of soil development, and certain profile characters in the mature soils of southern Illinois The profile characters chosen for study were texture, structure, color, consistence, and depth to horizons. If a constant relationship exists between slope and soil characteristics in any given region, and if the relationship be known, such knowledge would be of material aid in the mapping of soils. It should, moreover, be very useful in preliminary scouting in connection with finding suitable locations for experiment fields and in explaining soils to farmers and others not familiar with profile characteristics, in that slope is an observable feature familiar to all. Greater accuracy and rapidity in differentiating soil profiles could be attained through the use of an additional easily observable feature, such as slope, if it is correlated with profile characteristics, as only a very small fraction of the soil profiles in any given area can be examined even in the most detailed work.

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[2] Assistant Chief and Chief in Soil Survey, respectively.

[3] Reference by number is to "Literature Cited," p. 262.

LITERATURE

The influence of slope of the land surface on soil character is frequently mentioned in the literature, but only general relationships are stated. Neither drainage nor slope of the land surface has been used as a basis of group differentiation, even though all the early schemes of soil classification were based upon some feature or features external to the soil. The modern classification schemes, such as the Russian reported by Glinka (1), and that of Marbut (6), have recognized drainage and slope of the land surface as environmental factors influencing soil character, but have not used these environmental factors, or differences in soil character produced by them as the basis of any grouping. The Russian classification scheme is based upon the existence of broad geographical belts differing in temperature and rainfall. The highest categories in Marbut's classification scheme are established upon likeness and differences in the occurrence of certain profile characteristics which are chiefly the product of the operation of temperature and rainfall factors. The climatic factors, temperature and rainfall, are very important in soil development, but their use as a basis of classification has emphasized their importance to the disadvantage of other environmental factors and, therefore, the quantitative relationship of slope of the land surface to soil character has not been worked out.

In describing the characteristics of two widely distributed soil types in the Ozark region of Missouri, Marbut (7) states that one has a light gray surface horizon and a compact, thick, plastic, lower horizon. The other, developed from the same parent material, under similar vegetative cover and climate, has a shallow, yellowish colored surface horizon, and a slightly compacted, thin, lower horizon. The local occurrence of each, as far as topography is concerned, is characteristic. The former is stated to occur on a relatively flat surface, the latter always on slopes. He attributes this difference in profile development to a difference in age, the first having accumulated on the remnants of a former widespread plateau, the latter on the rolling surface following erosion of the plateau. The differences in the two profiles could be interpreted as being due fundamentally to differences in environment rather than differences in age. The features marking the poorly drained profile, according to the latter interpretation, could not develop under good drainage regardless of age, neither could the features marking the well-drained profile develop under poor drainage. Marbut (8) notes variation in the texture and consistence characteristics of soil profiles developed under similar climatic conditions and from the same parent rock but under different topographic conditions.

Koehne and Niklas (5) report that they observed considerable difference in the size of weathered rock particles in soils derived from material of the same geological origin but on different slopes. They suggest that variation in slope may also be expected to affect the chemical weathering of the material and the ultimate reaction of the soil.

King (4) long ago stated that the degree of inclination of the land surface and the direction of slope exerts a marked influence upon the temperature of the soil, particularly its diurnal range. As temperature is one of the important factors in the environment of soil development, temperature variations produced by differences in slope would be expected to affect the development of some soil characteristics. Slope and vegetation would, moreover, control to a considerable extent the amount of water entering the soil.

Glinka (1, pages 72-75) describes the characteristics of Podsol soil profiles developed in a restricted area in depressions, on flats, and on gently rolling surfaces, as having differences of considerable magnitude. He attributes these differences to variations in environment caused by differences in slope The topographic occurrence of the typical Grundy silt loam in Nebraska is reported by Hayes (2). He states that definite variations in some soil characters occur in profiles developed on other than typical Grundy topography. Norton and Smith (10) report that a good correlation exists between drainage and slope and some important characters in the soil profiles of southern Illinois. Although none of this work has definitely stated a quantitative relationship between slope and soil character, it has established slope as a factor influencing soil development.

PROCEDURE

The area of that portion of the state of Illinois bounded mainly by the 38th and 39th degrees of latitude and the 88th and 89th degrees of longitude was selected for this study. The soil material from which the profiles of this area were largely derived was loess. Two shallow deposits of this material occur, separated by an interval of weathering accumulated during Sangamon and Peorian Interglacial periods, over the weathered Illinoisan glacial drift. In a mature profile, this mode of origin should be of little significance; but in a youthful profile or in one which is being rejuvenated by a change in environment, as for example, a change in drainage, it probably would result in a difference in some of the characters in the profile. Many so-called "slick spots," which are interpreted as having been developed by the weathering of a shallow, calcareous loess superimposed on the weathered and impervious drift, occur in this area. Removal of bases in the overlying material by leaching in response to the forces of the humid temperate climate of this region was interrupted in these spots owing to the existence of a continued high water table which was caused by the impervious nature of the thick compact plastic zone of the underlying weathered drift. The bases accumulated at certain places in the profile of the overlying material and have had great influence on its characteristics. Although these facts were known at the time the work reported in this paper was done and the areas affected by profile rejuvenation and by "slick spots" were avoided whenever possible, it is likely that they account for some of the variation in the profiles examined because of the impossibility of recognizing them at certain places where they closely resemble the usual soil profile.

Other factors which have made up the environment of the area in which the profiles studied were developed are best described by noting each separately. The topography of the area was an unusually flat plain following the withdrawal of the Illinoisan ice sheet lying about 500 feet above sea level, and broken occasionally by low drift knolls and in the southern part by preglacial ridges. Drainage has since dissected the southern half of the area until the upland divides are comparatively narrow and the valleys broad, while in the northern half the divides have remained broad and the valleys narrow. The mean temperature in this area for the past 60 years has been about 55° F; the mean annual rainfall, 41.5 inches; and the average growing season about 188 days (9). The ground is seldom frozen for more than six weeks throughout the year, so that the processes of leaching and decomposition have been almost continuously active. A forest vegetation, consisting chiefly of oak, hickory, elm, and ash, has followed the advance of drainage and overspread most of the upland in the southern half, but is confined to narrow belts adjacent to stream courses in the northern half, leaving many broad, flat prairies. A fair growth of grasses covered these prairies prior to their occupation by man. No records are available, but it is safe to assume that the humidity and evaporation on similar areas over this entire region has been almost constant.

An effort was made to choose locations on virgin soils for measurement and observation, or upon soils which had been undisturbed for a considerable period. Virgin timbered areas were selected whenever possible. In prairie areas sodded strips along highways and occasionally fields in permanent pasture were used. The slopes were measured by the use of a hand level. The method of using the hand level was as follows: The eye of the observer, during each observation, was kept at a given constant distance from the surface of the ground by assuming a squatting position and resting the elbow on the knee. The object to be sighted on was a sharp-pointed rod with a cross arm so placed that it was at the same height as the observer's eye when the rod was set in the ground. The usual distance from the observer to the sight rod was 25 to 30 feet The accuracy of this instrument in measuring slope rests largely with the individual using it. Its accuracy in reading to a slope of 10′ was checked by the use of a surveyor's level, rod, and chain. In 40 trials it proved 97% correct. It is safe to assume that less than 5% of the readings were in error in excess of 10′, and that in none was the error greater than 20′.

The depth to horizons and description of characters in the profile were obtained from excavations made with a spade. Three excavations for each measured distance were made, one each at a quarter of the total distance from the observer to the point of observation, the other midway between the two points. If similar data were not obtained from these three excavations, the location was not used. As the locations selected were first carefully investigated as to uniformity of slope, erosion, disturbance by animals, or other irregularities, they seldom had to be abandoned The depth to horizons was measured with a rule. The friable horizons near the surface were separated at the point where a distinct change in color occurred. This change in color is due to a difference in the organic-matter content of the horizons, and is characteristic of all soils in this region. The friable surface horizons were separated from the zone of accumulation and compaction in those profiles developed on rolling topography under good drainage at a point where a distinct difference in the size and shape of the structure particles was observed. This point was also marked by a greater resistance of the aggregates to rupture. In those profiles developed on level to undulating topography under poor drainage, this separation was made at a point where the distance between the column heads narrowed, as indicated in Fig. 1.

EXPERIMENTAL RESULTS

The result of each individual measurement of slope in minutes with the corresponding depth in inches at which the zone of accumulation occurred is reported in Table 1. The depth to the zone of accumulation is recorded to the nearest inch, and as previously noted, slope

TABLE 1.—*Relation of slope to depth from surface at which the zone of accumulation occurs.*

Depth in inches	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200	201-210	211-220	221-230	231-240	241-250	251-260	261-270	271-280	281-290	291-300	301-310	311-320	321-330	331-340	341-350	351-360	361-370	371-380	381-390	391-400	401-410	411-420	421-430	431-440	441-450	451-460	461-470	471-480	Mean in minutes	P.E. of Mean+[1]
28	1																																																0	- -[1]
27	3	1																																															2	- - -
26	6	1																																															2	- - -
25	11	5	1																																														4	1.32
24	20	13	2																																														5	.96
23	9	12	5	2																																													10	1.24
22	3	4	8	4	1	2	1	1																																									25	2.95
21		2	5	19	10	7	5	2																																									38	1.65
20			2	9	30	11	8	4	3																																								46	1.41
19				6	11	21	11	5	4																																								52	1.36
18				2	6	9	10	11	8	4	4	2	1																																				68	2.15
17				1	2	2	4	7	6	9	12	4	3	3	1																																		88	2.64
16						1	2	3	3	5	5	6	9	7	4	1																																	107	3.03
15								1	2	1	3	5	6	9	7	2	2	1	1																														125	2.92
14												2	3	2	5	3	5	6	4	2	2	1	1																										139	3.80
13														2	1	1	2	2	8	3	4	3	3	2	1																								188	3.98
12																	1	2	1	1	2	1	3	5	4	3		1	1																				222	4.89
11																								1	1	1	1	5	1	1	1	1																	270	4.44
10																												2	2	2	2	3	1	2	2	1													307	5.19
9																																	1			1	2	1	2		1				1					373	- - -
8																																															1		1	460	- - -
Mean in inches	24.4	23.6	22.1	20.5	19.7	19.4	18.9	18.2	18.0	16.8	16.7	16.0	15.7	15.3	14.9	14.6	13.8	13.5	13.3	13.1	13.0	13.0	12.7	12.1	12.0	11.7	11.0	10.9	10.8	10.5	10.3	10.2	9.5	10.0	10.0	9.5	9.0	9.0	9.0		9.0				9.0		8.0		8.0		
P.E. of [1]+Mean	.14	.16	.20	.15	.10	.13	.17	.21	.21	.15	.14	.21	.18	.19	.18	- -[1]	.23	.24	.16	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -		- -				- -		- -	- -	- -		

Slope in Minutes

[1] Probable error calculated only on 10 or more individuals

measurements are to the nearest 10′. In accordance with this method of reading slopes, and for convenience in establishing a mathematical relationship between the degree of slope and depth to the zone of accumulation, the readings are grouped into classes with a 10′ range. The mean depth in inches of horizon occurrence for each group of slopes and the mean slope in minutes for each depth at which the zone of accumulation was found to occur, with their probable errors, were calculated from the individual figures Probable error for any mean was calculated only when 10 or more individuals could be used.

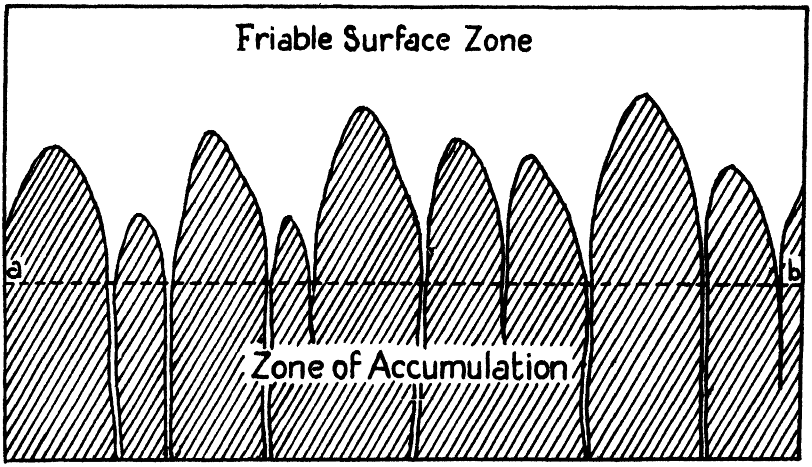

FIG. 1.—The line a–b shows the plane of separation between the friable surface horizon and the zone of compaction consisting of plastic clayey material in columnar form.

Peters' formula was used to calculate probable errors, as follows;

$$P.\,E. = \pm\, 0.8453\, \frac{\Sigma v}{n\sqrt{n-1}}.$$

A mathematical expression of the correlation between slope and the depth to the zone of accumulation was worked out by the use of Kelley's (3) correlation ratio method. The formulae used and result obtained follow:

Let x represent the means of the arrays of slope, and y represent the means of the arrays of depths. By using the formulae $\eta\, x = \sqrt{\frac{Fy(\overline{yx}-\overline{x})^2}{N}}$, and $\eta\, y = \sqrt{\frac{Fy(\overline{xy}-\overline{y})^2}{N}}$, and γ = class diff. $\sqrt{\frac{\Sigma d^2 f}{N} - \frac{(\Sigma df)^2}{(N)}}$, and $\gamma\eta = \frac{1-\eta^2}{N}$, we obtain:

$\gamma y = 10\sqrt{\frac{177501}{622} - \frac{(9079)^2}{(622)}} = 85.04$, the $\gamma x = 1\sqrt{\frac{10353}{622} - \frac{(2057)^2}{(622)}} =$ 2.3892, and $\eta y = \sqrt{\frac{4146548.89}{622}} = 81.6484$, and $\eta x = \sqrt{\frac{3549.95}{622}} =$ 2.2850. Then $\frac{\eta y}{\gamma y} = \frac{81.6484}{85.04} = 0.9601 \pm .0031$, and $\frac{\eta x}{\gamma x} = \frac{2.2850}{2.3892} =$ $0.9564 \pm .0034$.

Field methods in soil science are not well enough developed to measure quantitatively many of the characters in the profile. Therefore, only a qualitative description of the texture, color, structure, and consistence characteristics of each horizon was made in the field. The description of these characters in the profiles and the corresponding slope on which each occurred is given in Table 2. The expression of these characters on all slopes was such that they could be logically grouped into five classes, each having rather definite topographic limits.

DISCUSSION OF RESULTS

The differences in depth and characteristics of the horizons, as noted in Tables 1 and 2, and illustrated in Fig. 2, are thought to have arisen because of differences in the environment under which the various profiles were developed. The nature and action of the soil-forming forces constituting the environment vary with variations in slope Probably the most important effect of slope is its influence on the moisture condition of the profile. Although vegetative cover, the amount of rainfall, the time of year it comes, the rate at which it falls, and the character of the soil are factors in determining the percentage of runoff, yet the general statement can be made that the amount of runoff increases as the slope increases It follows that the amount of moisture entering the soil in any given region decreases as the slope increases.

The application of the correlation ratio method to the figures in Table 1 shows that a close relationship exists between the slope and the depth at which the zone of accumulation has developed. The correlation is negative, but high, that is, as the slope increases the depth to the zone of accumulation decreases This relationship, however, is not linear but parabolic, as can be seen from the data in Table 1. The depth to the zone of accumulation on a slope of 0.5% is about 23 inches, while on a slope of 3.5%, it is about 16 inches.

TABLE 2.—*The thickness, texture, color, structure, and consistence characteristics of horizons of the soil profile arranged in definite topographic and drainage groups.*

Topography and drainage	Horizon			Profile characters		
		Thickness	Texture	Color	Structure	Consistence
Very rolling 4° to 8°	Upper horizon	9 in.	Silt loam	Reddish yellow with brown cast	Laminated	Friable
7 to 14% Excellent	Zone of accumulation	9 in.	Silt loam	Reddish yellow	⅜ to ½ in. subangular to rounded	Friable
Rolling 2° to 4° 3.5 to 7%	Upper horizon	13 in.	Silt loam	Upper—brownish yellow Lower—yellow with reddish cast	Laminated	Friable
Good	Zone of accumulation	11 in.	Silt loam	Reddish yellow	¼ to ½ in. subangular	Friable, non-plastic
Gently rolling 40″ to 2° 1.2 to 3.5%	Upper horizon	17 in	Silt loam	Upper—brownish yellow Middle—yellow Lower—gray with yellow cast	Upper—laminated Lower—structureless	Friable
Fair	Zone of accumulation	14 in.	Clay loam	Yellow splotched with gray	Slightly columnar ⅛ to ⅜ in. subangular	Medium compact and plastic
Undulating 10 to 40′ 0.3 to 1.2%	Upper horizon	21 in.	Silt loam	Upper—brownish gray Middle—gray Lower—light gray	Upper—laminated Lower—structureless, ashy	Friable
Poor	Zone of accumulation	20+ in.	Heavy clay	Gray streaked with yellow	Columnar ⅛ to ½ in. subangular	Compact and plastic slowly pervious
Level Less than 10^1 Less than 0.3%	Upper horizon	24 in.	Silt loam	Upper—gray Middle—light gray Lower—ashy white	Upper—laminated Lower—structureless, ashy	Friable
Very poor	Zone of accumulation	20+ in.	Heavy clay	Pale gray	Columnar, ¼ to ⅝ in., subangular to angular	Very compact and plastic, very slowly pervious

With a further increase of 3% in slope, the depth to the zone of accumulation is about 12 inches. That is to say, a difference of 3% in slope on the lower gradient is associated with a difference of 7 inches in the depth to the zone of accumulation, while on the steeper gradient a like difference in slope is associated with a difference of only 4 inches in depth to the zone of accumulation This relationship is illustrated in Fig. 2. A few profiles examined on slopes of 14% or more, which were developed under a grass vegetation, were eroding faster than the profile was being developed The same thing was found to be true on slopes of 17% or more under a forest vegetation.

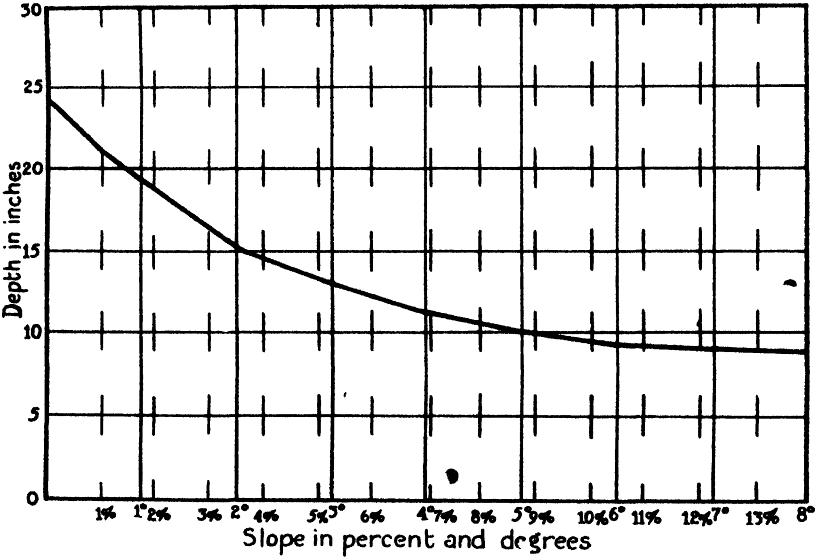

FIG. 2.— Curve of relationship between slope and accumulated zone.

The data obtained from observation of the texture, color, structure, and consistence characteristics of each profile in the field naturally fall into a grouping such as shown in Table 2. The definite limits of each group, as shown in the left-hand column, imply that these divisions occur in nature. This, however, is not the case. The figures given represent the slope about midway between the two slopes on which the characteristics of different soil types are typically expressed.

The texture of the surface horizon in all profiles is a silt loam irrespective of the slope on which it developed. The texture of the zone of accumulation changes markedly from that of a silty nature in profiles developed on rolling topography to that of a heavy clay in profiles developed on nearly level topography.

The thickness and color of the upper portion of the surface horizon, the organic layer, change from moderately thick, brownish yellow with a reddish cast, to relatively thin, brownish gray as the slope decreases. The change in the lower portion of the surface horizon is very pronounced and quite characteristic. Those profiles developed on very rolling topography have a reddish yellow lower surface horizon. As the slope decreases the reddish cast is lost, and as the level topography is approached, gray replaces the yellow. On level topography, an almost white layer has developed.

All profiles examined had a laminated or plate-like structure extending from the surface down to a depth of 4 to 10 inches. The depth to which this laminated structure extended seemed to have no relation to the topography on which the profile was developed. It generally extended somewhat deeper in the profiles developed on nearly level topography; however, many exceptions to this were found. In those profiles developed on slopes of 3.5% or more at the base of the laminated structure, the laminations faded abruptly into flake-like structure particles ⅛ inch or less in thickness, ¼ to ⅜ inch wide, and ½ to 1 inch long. One-fourth inch subangular structure particles were found to occur immediately below the flake-like structure particles. These structure particles become more distinctly developed and somewhat larger with increase in depth through the zone of accumulation. In those profiles developed on slopes of 1.2% or less, the laminated structure faded gradually into an ashy gray, structureless mass. Fig. 1 indicates the appearance of column heads near the base of this structureless mass. The columns widen with increase in depth, but remain heavily coated with the ashy gray material through the zone of accumulation. The structure particles in the columns are somewhat angular, and usually ½ to ¾ inch long, and ¼ to ½ inch in the other two dimensions.

The consistence of the surface horizon in all profiles can be termed friable and non-plastic. That of the lower portion in those profiles developed on level topography could more aptly be called ashy. The consistence of the zone of accumulation is friable and non-plastic in profiles developed on very rolling topography, and is very compact, highly plastic, and very slowly pervious in those developed on level topography.

SUMMARY

The data presented indicate that a good correlation exists between topography and the depth to the zone of accumulation, and four important characteristics of the soil profile. As the slope and drainage increase, the depth to the zone of accumulation decreases, the texture changes from a heavy clay to a silt loam, the color from a light gray to a reddish yellow, the structure from large angular aggregates which are columnarly arranged to relatively small subangular particles, and the consistence from highly compact, plastic, and slowly pervious to friable, loose, and open, irrespective of the rate or amount of surface material removed by erosion or accumulated by deposition.

A slight change in the slope on nearly level topography has much more effect on the profile than an equal change on rolling topography.

The soil of this region erodes more rapidly than the profile is developed on slopes of 14% or more under grass vegetation, and on slopes of 17% or more under forest cover.

Slope of the land surface is a very important feature in differentiating soil types in the field, and can be used extensively in mapping

The characteristics in the profiles studied indicate that there may be two regional profiles in this area which have developed in response to two different environments. The one developed on level topography under poor drainage has a thick, gray, silty surface horizon, and a gray, thick, compact, highly plastic zone of accumulation. The other, developed on rolling topography under good drainage, has a thin, reddish yellow, silty surface horizon, and a thin, friable, nonplastic, reddish yellow, silty zone of accumulation.

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CRITICISM OF THE LIMITATIONS OF THE STATISTICAL METHOD[1]

J. ARTHUR HARRIS[2]

Biological phenomena, as they may be observed under natural conditions and as they must be dealt with under the partially controlled conditions which we call agriculture, are so complex that many different kinds of technic must be employed in amassing the data on which conclusions of value may be based With the data of observation or measurement by any kind of technic in hand, the investigator seeks to formulate generalizations or laws.

It is a remarkable fact that while no one now objects to the development of refined methods of experimentation and measurement, there has been a hoarde of critics of the attempts which have been made to develop a logical, trustworthy, and workable system for expressing the data of observation and experimentation in succinct generalizations, with criteria of their dependability. The science of biometry has developed under a steady fire of such criticism The contribution on the desk at the moment is by Professor Salmon [3]

With some of the things which Professor Salmon says it is not worth while to disagree. Others seem to me wholly reactionary and, if too literally followed, prejudicial to progress in agricultural science. Since some of his arguments appear to be convincing, when only hastily and superficially considered, it is desirable to examine them briefly, with a view to appraising their soundness.

1. I am quite in accord with Professor Salmon when he says that we have no observational data showing that the sun has risen every morning for a hundred million years. I also agree with his conclusion that our confidence in the sunrise is founded on known laws. I cannot agree with him that the methods by which these laws were determined were not fundamentally the same, though different in detail, from those which are employed in the modern higher statistics. The pure mathematics which underlies both the older astronomy and the new statistics is a very old science. It is by no means easy to say where the contribution of one branch ends and that of another begins. According to Professor Salmon, "To question the sunrise is to predict a cosmic catastrophy." Hence, I shall not venture to question it.

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[1] Contribution from the Department of Botany, University of Minnesota, Minneapolis, Minn. Received for publication October 14, 1929.

[2] Head of Department.

[3] SALMON, S. C. Why we believe. Jour. Amer. Soc. Agron., 21:554–559. 1929.

2. I have no quarrel with Professor Salmon when he says that the statistical method has suffered mostly from its friends, if by friends he means those who attempt to use these methods without adequate understanding of them He is also right, but by no means original, when he says that, "There is . . a well-defined need for information and clear-cut statements regarding the limitations and the assumptions, tacit and otherwise, that are involved when any statistical formula is applied to a particular set of observations." This is the very point which serious biometric workers have persistently emphasized [4] It is the necessity for providing methods which will meet the requirements of the whole range of conditions of empirical data that has made the literature of statistics as extensive as it is, and has made it necessary for specialists to devote their attention to the problems of the application of the methods.

3. Referring to Pearl's two series of mean ages at marriage each of ten averages based on five names from *Who's Who*, he says, "Unfortunately he made no calculation to prove his point, since if he had done so, he would have found a significant correlation between the two series of data."

There is no necessity to detail here all the reasons why no trained statistician would consider such a correlation significant It is sufficient to note the quite obvious fact that there is no basis in "common sense and judgment" for determining a correlation between such pairs of random drawings from *Who's Who* at all. The data are not homologous with most experimental results to which correlation methods would be applied, because the two series of random samples are both arranged in a wholly arbitrary order. There is no logical reason why the first average of a second series *of random samples* should be aligned with the first average of a first series of random samples, and so on. All, if properly taken, are by definition wholly independent. To determine a correlation between two such series is quite comparable to taking 10 plats of wheat at random at the Kansas Agricultural Experiment Station and 10 at random at the Iowa Agricultural Experiment Station, giving the plats of both series arbitrary numbers, and then determining the correlation between the yields of the plats which happen to bear the same serial number.

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[4] How little Professor Salmon knows of the meticulous care with which constructive workers in the field of the modern higher statistics have stressed the assumptions and the limitations of the formulae is shown by his reference to the "master," E. B. Wilson, whose "viewpoint is especially encouraging to those who believe that the development of modern statistical methods—wonderful though it has been—has not as yet made it unnecessary to use common sense and judgment in interpreting experimental results."

If one feels impelled to determine correlations between series of random samples, why not determine all the possible correlations before deciding that a coefficient measuring the relationship between them is "significant"? Either of the two series of average ages from *Who's Who* can be arranged in any one of $(n!) = 3,628,800$ orders, all of which are equally logical. Since there are two such independent series of 10 samples, a total of $(n!)^2 = (3,628,800)^2$ correlations might be determined from the series of data Professor Salmon determines a single one of these $(3,628,800)^2$ possible correlations and asserts that it is "significant." There is no logical reason to calculate a coefficient of correlation for one arrangement of the random drawings and not to determine the coefficients for all the other $(3,628,800^2—1)$ possible arrangements. It is idle to assert that one correlation is "significant" and leave out of account the $(3,628,800^2—1)$ correlations which he has not determined.

Thus this case, to which Professor Salmon devotes so much attention, has no value as indicating the limitations of the statistical method, but it does illustrate the danger of loose thinking in the statistical field.

4. I cannot venture to criticize Professor Salmon's next line of argument, for the simple reason that I cannot understand it. He says, "As a matter of fact, conventional statistical proof of itself is seldom satisfactory. In the first place, the additional evidence which it supplies is negative" Does he mean that an additional positive quantity has a negative sign? Or does he mean that statistical evidence is the reverse of what is assumed to be? Or does he mean that additional evidence is less than no evidence at all? I cannot clear up the mystery by following him farther when he says, "It shows not that an observed result is due to an assigned cause (as many seem to think), but merely that the observed result probably is or is not due to a definite, limited kind of error." I have no ghost of an idea as to what this means, but I do know that as a statistician I have never conceived of observed results—other than the special case of errors of measurement—being due to "a definite, limited kind of error." And I am not at all convinced that, in general, results are due to errors, by his assurance that, "So far as may be deduced from the statistical treatment, the result may have been due to other kinds of error or to any number of other causes which may or may not be known to the investigator." Professor Salmon's arguments here are not the "clear cut statements" for which he sees such great need. They are merely a meaningless jumble of words

5. Professor Salmon seems to me to have missed the entire point of statistical reasoning when he tells us how easy it is to find out how many colored balls there are in a bag by counting all of them instead of a part. Statisticians often consider drawings of balls from a bag of known content to establish theoretical relationships, but in the field of practical statistics we cannot know what the actual composition of the bag is For example, we shall never know exactly the average yield of Turkey or Kanred wheat in Kansas, simply because the whole area of the state cannot be planted to the two varieties and the yield measured to find out. The best that can be done is to grow limited experimental areas of the two varieties and then on the basis of the means and their probable errors decide which of the two varieties is the most probably suited for the practical agriculture of the state. As far as I am aware no "fundamental principles" as yet known make it possible to make prediction without actual experimentation

6 As far as I can make out, Professor Salmon is arguing for the pinning of our faith to great fundamental principles and laws. Those who used to try to decide whether a bucket of water would weigh more with a fish in it than without attempted to do the same thing. In agricultural research we have not yet reached the stage where we can afford to decide important questions on the basis of our "knowledge of the principles and laws which underlie the phenomena in question" without subjecting our problems to actual experimental test and the determination of the probable errors of our experimental results. As a matter of fact, gross blunders have been made in agriculture because it seemed reasonable from our "knowledge" of underlying laws that this procedure or that should be followed.

It is worth while at every stage to check the workings of "laws" in each specific case. For example, chemistry has a great system of "underlying principles and laws." Analytical methods are founded on these principles. Can we, therefore, dispense with statistical tests of the validity of our analytical results? In this laboratory we have recently had occasion to consider large series of chemical analyses from laboratories where the "underlying principles and laws" are well recognized. The statistical analysis of the data shows gross and hitherto unexpected sources of error in the results.

I do not want to be misunderstood on this point. The discovery of fundamental laws is the objective of scientific research. The application of these laws in the solution of other problems, theoretical and practical, is the obvious course to follow. But to argue that at this stage of agricultural experimentation we can depend on fundamental principles and laws to such an extent that we can omit the statistical analysis of our data and the determination of the probable errors of our experimental results seems to me to be a dangerous course

7. I cannot agree with Professor Salmon that, "Most experiments afford evidence supplementary to the main issue which is of the greatest value in arriving at a reasonable interpretation of the results but which, for various reasons, is not readily included in a statistical analysis." This may be true of careless experiments, but in careful work the methods of experimentation and measurement should and can be so refined that the accessory data may be included in the statistical analysis of the results. Possibly in some cases the statistical theory is not yet adequate, but if this limitation obtains, the mathematical theory should be developed to meet the needs

8. There is a remarkable inconsistency in Professor Salmon's following arguments. He criticizes the statistical method because he says that it cannot lead to certainty He says that it would be much more satisfactory to know that all the aces had been withdrawn from the pack "thus eliminating all doubt" I believe that in the early days of the West some of the experts actually tried this out experimentally by putting an extra ace up the sleeve, to be used in case of emergency, but even this precaution did not always prove to be "satisfactory."

In the adjoining paragraphs, however, he urges that "statistical analysis in many cases affords unsatisfactory proof" because "many experiments, especially field experiments in agriculture, do not furnish results which readily lend themselves to statistical manipulation because of bias, lack of randomness, or paucity of observation."

Now if agricultural experimentation is so faulty (because of "bias, lack of randomness, or paucity of observation") that the data are not good enough for statistical treatment, how can we waive a demand for statistical treatment (including the determination of probable errors) and accept these same data without statistical treatment as "reasonably dependable and useful" and blindly assume that such data can serve as a "basis for action or specifiadvice?" Professor Salmon has a perfect right to assert (a) that experiments are conclusive and that statistical methods need not be applied or (b) that experiments are so poorly conducted that statistic cal methods can not be applied, but he overwhelms us with the weight of his logic when he argues against the statistical method on the ground that we can arrive at trustworthy experimental results and hence do not need to apply the statistical method and also on the ground that the data of experimentation (specifically agricultural experimentation) are too faulty to be analyzed statistically.

9. Nothing is to be gained by criticisms of the statistical method on the ground that agricultural experimentation is too poorly conducted to justify the serious analysis of the data. The obvious course is for experimentalists to eliminate bias and to increase the number of observations so that the results can be admitted to be of value.

Professor Salmon's pessimism concerning the data of agronomic experimentation is not at all justified by my own experience, both in the field and in the statistical laboratory. Much of the work is unquestionably bad, but with reasonable care and with an adequate understanding of the biometric requirements which should be met, it is possible to organize and conduct field experiments in such a way as to make possible the application of the powerful methods of biometric description and analysis. I have, indeed, ventured to suggest that by a proper combination of agronomic, physicochemical or physiological, and biometric technics, it will be possible to investigate in the field many problems which are ordinarily considered to be only amenable to investigation under the controlled conditions of the laboratory.

It seems unnecessary in this place to cite evidences in support of this statement. Ample illustration of the power of the statistical method in the analysis of agronomic data are already available to the readers of this JOURNAL in summaries of my own[5] and in innumerable papers by other workers which cannot be reviewed here.

10. As I have stated above, there are points on which I am fully in agreement with Professor Salmon. It is quite natural that in this paper I should have stressed those on which I think his advice is likely to do harm to agricultural research. It would be idle and ill-advised to urge that all agricultural problems be immediately attacked by statistical methods as this term is conventionally understood. It would be reactionary to suggest that we ignore the established (or supposedly established) laws of physics, chemistry, or biology. But we should remember that in the field of research, the agriculturist, like the physicist, chemist, or biologist has a two-fold task. He must first accumulate a number of observations or measure-

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[5] HARRIS, J. ARTHUR. The service of statistical formulae in the analysis of plat yields. Jour. Amer. Soc. Agron., 18:247-273. 1926.

HARRIS, J. ARTHUR. Mathematics in the service of agronomy. Jour. Amer. Soc. Agron., 20:443-454. 1928.

ments which will justify the drawing of broad generalizations concerning the phenomena with which he is dealing. He must then seek to describe his results by generalizations or laws. In the drawing of these generalizations or in the formulation of these laws (many of which may serve as a basis of recommendation for procedures in practical agriculture), he should seek to determine by as trustworthy criteria as we can assemble—in short, by probable errors—whether his experiments are really proving their points

THE STATISTICAL METHOD: A REPLY[1]

S. C. SALMON[2]

The longer one lives, the more one is impressed with the infinite capacity of the human mind for misunderstanding and the great difficulty in expressing one's thoughts in a way that will not be misconstrued The paper in question lay on the writer's desk a year before it was submitted for publication and was read and approved by several persons well acquainted with his viewpoint regarding statistical methods Yet in spite of several inferences and one specific statement to the contrary, Dr. Harris appears to believe that it was the writer's intention and purpose to criticize the statistical method as such He apparently acquired this impression by selecting examples which were intended as illustrations of particular errors rather than as illustrations of a misuse of the statistical method as a whole Thus, in my paper, reference was made to the correlation between age at marriage of two groups from *Who's Who* to show that Pearl, in arriving at a conclusion, had *depended* upon his preconceived (and correct) opinion rather than upon the statistical method. If the illustration is faulty because not analogous to experimental data, the fault would seem to lie with Pearl rather than with the writer.

It seems unlikely that anything useful will result from attempting further to answer Dr. Harris' criticisms If he has "no ghost of an idea" as to the meaning of portions of my paper, it is at least doubtful whether a second attempt on my part would clarify the situation. It is decidedly important, however, that the issue be clear cut and definite. Agronomists are responsible for the expenditure for research of large sums of public money. The farming public is looking to them as never before for reliable information on every conceivable subject having to do with growing crops. If there is anything "dangerous" in the viewpoint expressed by the writer, agronomists certainly will be interested to know about it and to have the evidence that it is dangerous placed before them for their study and evaluation.

What, then, is the issue involved? Merely, (a) Is it true that field experiments "are not of sufficient practical value" to justify their expense? (b) Are such experiments "discreditable to agronomic science" if not interpreted statistically? (c) Is "an experiment which takes no account of the probable error as likely as not to lead to incorrect conclusions?" The question is not whether the statistical method is useful—that is admitted—but whether it is so vital and so essential that every other consideration must be waived in its favor. To these questions, the writer, without hesitation and without equivocation, would give a negative reply, even though he finds himself opposed by so eminent an authority as Dr. Harris. To do otherwise is to discredit a major part of the experimental work in agronomy in the United States and this, the writer believes, no competent authority at all familiar with the situation would care to do.

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[1] Contribution No. 187 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication November 3, 1929.

[2] Professor of Farm Crops.

In meeting this issue, it must be kept in mind that the agricultural experiment stations the country over are insistently confronted with the need of investigating a continuously increasing number of problems of greater and greater complexity. The demands upon them tend to increase in a geometrical ratio, while the means for serving those demands increase, if at all, in an arithematical ratio. The vital problem therefore, which confronts every experiment station and every investigator in them, is not merely how may an experiment be conducted so that chance errors may be evaluated, but how may it be conducted so as to solve the problem at hand with the least expenditure of time and money. Investigators charged with the responsibility of solving these problems should be in a position to use modern statistical methods when that seems the wisest thing to do, but they should not be compelled to face the alternative of using these methods or being discredited in the eyes of the scientific world.

Dr. Harris' observation that it would be "idle and ill-advised to urge that all agricultural problems be immediately attacked by statistical methods" may be interpreted to mean that he recognizes the difficulties involved in conducting many agronomic experiments and that he is not among those who consider an experiment of no value which does not have a probable error attached to the result. If so, there would seem to be no real difference between his viewpoint and my own.

THE INFLUENCE OF SEASON UPON THE DISINTEGRATION OF LIMESTONE IN SOIL[1]

W. H. MacIntire and W. M. Shaw[2]

The question is often asked as to the best period for the addition of limestone to the soil Recommendations upon this point are sometimes qualified with reference to the fertilizers that are to be used and the crop or rotation. In general, however, the advice is to apply limestone when it can be put on and worked in most conveniently.

It is conceded that the benefits from liming come after the added materials become fixed, or absorbed, by the soil. The influence of type and fineness of limestone upon its disintegration and conservation has been studied, but no report has been found concerning the influence exerted by season. The present experiment was planned to throw light upon that point

EXPERIMENTAL

An acid-reacting clay loam of the Hagerstown series was used to provide 18 pounds of soil—moisture-free basis—to each of 48 glazed earthenware pots of 2 gallons capacity. The pots were supplied with holes for drainage. One-half of the soil for each crock was added and tamped lightly. An asphaltum-coated disc of wire cloth was placed on the top of this lower layer, or half, to separate it from the upper layer. The limestone additions were made at the rate of 3,570 pounds of $CaCO_3$—2,000 pounds CaO-equivalent—per acre surface and mixed throughout the upper half of the soil to simulate the harrowing-in that would be given in the field. On the soil basis, the limestone additions were equivalent to 0.357%, or 3,570 pounds per 1,000,000 pounds of moisture-free soil. The addition was equivalent to about only one-fifth of the soil's absorptive capacity.

All of the 48 pots were embedded out of doors, the surface of the soil in the pots being on a level with that of the soil on the outside. On April 1, 1928, 24 of the crocks received additions of limestone or dolomite that were mixed throughout the upper half, or zone—six crocks each for limestone of 60- to 100-mesh and 20- to 40-mesh and the same for dolomite. One month after the April incorporation, four crocks, one for each separate of limestone and dolomite, were taken up. On the first of each succeeding month four

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[1] Contribution from the Department of Chemistry, University of Tennessee, Knoxville, Tenn. Received for publication October 14, 1929.

[2] Soil Chemist and Associate Soil Chemist, respectively.

more crocks, or one for each limestone and dolomite separate, were taken up until the end of the first six-months period. The other 24 adjacent crocks were left exposed to the same atmospheric conditions, without additions of limestone, until October 1, 1928. On this date they received the same additions of limestone and dolomite that had been given to the other 24 crocks six months previously. Both series were kept free of weeds but were not stirred during exposure.

As each set of four crocks was sampled during the 12-month period, the entire upper half, or zone, of each crock was dried thoroughly, mixed, and preserved for analysis to determine the amount of added carbonate that was still present. Fifty-gram charges of the original acid soil were used to obtain a carbonate-CO_2 blank. This constant was subtracted from the carbonate determinations made on 50-gram charges in duplicate for the soil of each crock The value thus obtained was subtracted from 0 357% constant to determine the disintegrated fractions of the added limestone or dolomite

DISCUSSION

The two periods, April to October and October to April, were considered as representing spring-summer and fall-winter exposure. The results, shown in Table 1, give the successive monthly carbonate values. The cumulative values are shown as pounds of $CaCO_3$-equivalence, in Fig. 1, together with the precipitation by months. The total of 63.17 inches is abnormal, since the average rainfall over a period of years is 51 inches.

As would be expected, the 60- to 100-mesh separate disintegrated more rapidly than did the 20- to 40-mesh product, for both high-calcic and dolomitic rocks, and during both seasons. The ultimate disintegration of the 20- to 40-mesh high-calcic limestone was also greater than that of the 60- to 100-mesh dolomite for both six-month periods. The disintegration brought about during the 6.09 inches of precipitation of April and the succeeding precipitations of 6.89 inches and 11.85 inches for May and June, respectively, were uniformly greater than those found to have occurred during the second initial three-month period of October with its rainfall of 4 29 inches and the next two months, November and December, with their respective precipitations of 3.87 inches and 1.82 inches. The cumulative curve for each limestone separate was an ascendent during the first three months of the April-October period, with a rainfall of 24.83 inches. On the other hand, there was no upward trend for the second and

TABLE 1.—*The influence of season upon the disintegration of limestone and dolomite additions in an acid clay loam.**

Material	Mesh	Carbonate changes expressed as percentage $CaCO_3$ equivalence																	
			Disintegrated			Disintegrated			Disintegrated			Disintegrated			Disintegrated			Disintegrated	
		Increase over control†	Soil basis	Addition basis	Increase over control†	Soil basis	Addition basis	Increase over control†	Soil basis	Addition basis	Increase over control†	Soil basis	Addition basis	Increase over control†	Soil basis	Addition basis	Increase over control†	Soil basis	Addition basis†
		April			May			June			July			August			Sept.		
Limestone . .	20–40	0.273	0.084	24	0.253	0.104	29	0.163	0.194	54	0.180	0.177	50	0.165	0.192	54	0.150	0.207	58
Limestone. .	60–100	0.213	0.144	40	0.170	0.187	52	0.145	0.212	59	0.120	0.237	66	0.125	0.232	65	0.095	0.262	73
Dolomite. . .	20–40	0.342	0.015	4	0.295	0.062	17	0.250	0.107	30	0.230	0.127	36	0.215	0.142	40	0.230	0.127	36
Dolomite	60–100	0.250	0.107	30	0.203	0.154	43	0.170	0.187	52	0.188	0.169	47	0.178	0.179	50	0.168	0.189	53
		Oct.			Nov.			Dec.			Jan.			Feb.			Mar.		
Limestone . .	20–40	—	—	(24)‡	0.270	0.087	24	0.270	0.087	24	0.230	0.127	36	0.215	0.142	40	0.225	0.132	37
Limestone. .	60–100	0.190	0.167	47	0.185	0.172	48	0.205	0.152	43	0.193	0.164	46	0.165	0.192	54	0.150	0.207	58
Dolomite. . . .	20–40	—	—	(11)†	0.318	0.039	11	0.320	0.037	10	0.300	0.057	16	0.295	0.062	17	0.280	0.077	22
Dolomite. .	60–100	0.268	0.089	25	0.265	0.092	26	0.280	0.077	22	0.260	0.097	27	0.270	0.087	24	0.300	0.057	16

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*A constant $CaCO_3$ equivalence of 3,570 pounds (CaO, 2,000) was used, representing 0.357% of the treated soil.

†The blank on the untreated acid soil was 0.05%.

‡Computed from the analyses of the two mixed samples.

third months of the October-November-December period, with its rainfall of 9.98 inches. During the second three months of the first six-month period there were smaller carbonate residues, higher temperatures, and dryer surface soil, with a rainfall of 12.02 inches. During the second three months of the second six-month period there were larger carbonate residues, lower temperatures, and wetter surface soil, with a rainfall of 16.34 inches. The disintegrations of two dolomite separates were not extensive during either of these two second three-month periods. On the other hand, the disintegrations of both limestone separates were greater during the second three-month period of the October-March period than during the second three months of the April to September period.

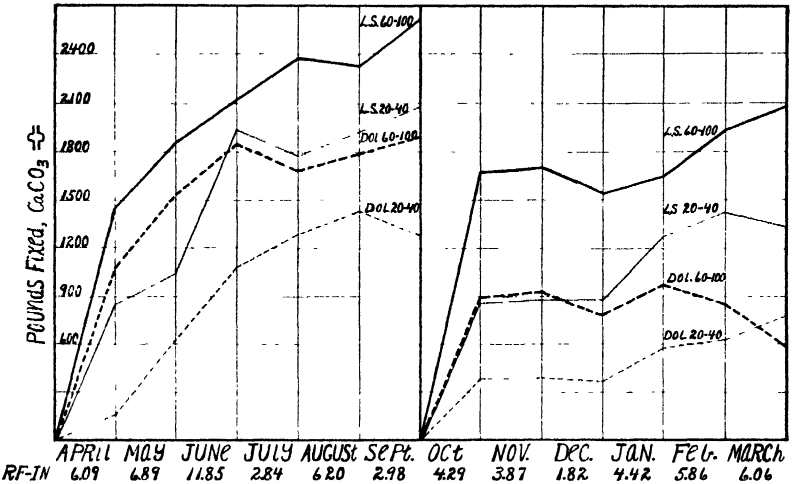

FIG. 1. The seasonal disintegration of 20- to 40-mesh and 60- to 100-mesh limestone and dolomite in an acid-reacting clay loam.

The October samplings of the 20- to 40-mesh limestone and dolomite crocks were inadvertently mixed. The carbonate content of the mixture was 0.285%, as compared to the average of 0 294% that was obtained from the two separately analyzed succeeding samples for November and also for December. This conformity and the lack of change during the 60-day period of November and December are taken to justify the respective values of 24% and 11% of the additions as two of the initial points in the graphing of the second series of curves in Fig. 1.

The determined points on the perpendicular month-lines do not show those requisite to give an invariable ascent in the trend of cumulative curves. The points that cause reversal in the upward trend are construed to represent errors that are inherent in the technic of this type of work, since the analytical work was repeated and proved in each instance.

The disintegration of limestone may be considered as primarily registering the periods when there were effective concentrations of CO_2 in the free soil-water and the duration of these periods. It appears that the supplies of CO_2 that were available during the spring months and during the intermittent moist periods of the summer months were more effective than those supplied during the fall and winter months. During the latter period the rainfall is not so readily evaporated and the intersticial pore spaces of the soil are filled with water within temperature ranges that are not conducive to the generation of CO_2, hence, the limestone disintegration, as controlled by moisture distribution and temperature range, was more extensive during the April-October period than during the period extending from October to April.

In addition, there is the effect brought about by the generation of other biological end-products. Previous experiments with the same soil have shown that additions of limestone and dolomite induce accumulations of nitrates and sulfates during the months embraced in the first six-month period On the other hand, the production of nitrates during the winter months was practically *nil*. Hence, for this soil, under fallow conditions, the disintegration of the limestone and dolomite is more extensive during the season when temperature and periodicity of rainfall produce the greater biological activities.

A FAILURE OF AUSTRIAN WINTER PEAS APPARENTLY DUE TO NODULE BACTERIA[1]

LEWIS T. LEONARD[2]

Two lots of Austrian winter pea plants were received from W. R. Dodson, Iberia Livestock Experiment Farm, Jeanerette, Louisiana, through H. N. Vinall of the U. S. Dept. of Agriculture, March 13, 1929. Both samples still had soil about their roots and were in fair condition, considering their long trip in the mail. One sample contained plants which were yellow and small, while the others consisted of fairly well-developed green plants. The plants in the samples were designated "abnormal" for the former and "normal" for the latter.

A rather complete history of the field from which these plants came has been kindly furnished by Mr. Dodson, and a tabulated summary of these data is given below·

Year	Crops	Fertilizer
1922–23	Red clover	Oyster shell lime and no lime
1923–24	Biloxi soybeans	None
1924–25	Corn and cowpeas	Nitrate of soda to corn
1925 26	Alfalfa varieties	Inoculation, lime and no lime
1926–27	Alfalfa varieties	Inoculation, lime and no lime
1927–28	Ootootan soybeans	None
1928–29	Austrian winter peas	None

It should be stated that no artificial introduction of inoculation was made either to the soil or the peas. It is evident from an observation of the roots, however, that the vetch strain of nodule bacteria was present in the soil

This field of Austrian winter peas exhibited good growth in spots, the greater part of the area being covered with sickly-looking plants. At the end of the season most of the latter were dead and the live plants were suffering from the effects of a drought

The bulk of the soil was carefully removed from around the roots of the samples and tested for acidity by the quinhydrone method. Similar determinations were made with a set of samples subsequently received. The abnormal samples gave H-ion concentrations of 5.5 to 6.5, while the normal ones gave 5.5 to 5.9.

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[1] Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Designated as No. 318 in the outside publication series of the Bureau of Chemistry and Soils. Received for publication October 31, 1929.

[2] Bacteriologist.

After the excess soil was washed from the roots, it became apparent that they exhibited no superficial signs of pea root diseases, but to make sure of this point they were taken to Dr. Charles Drechlser who kindly examined them for pathological conditions. His diagnosis was that they were especially free from disease.

Mr. Dodson in his letter transmitting these plants to Mr. Vinall mentions the possibility of the root nodule bacteria acting parasitically. In general, there was a clustering of large convoluted nodules around the crown of the normal plants, whereas on the abnormal plants they were of a small single-lobed type and quite well distributed over the root. This condition in connection with the background of previous observations strengthens the theory of parasitism or of the presence of non-beneficial nodule bacteria. To determine whether this was the case, isolations were made from nodules from each kind of plant.

After purification by plating these cultures, three strains from each type of plant were applied to sterilized Austrian winter pea seed planted in sterilized washed sand in small jars in the greenhouse March 21, 1929. These jars were first watered with Bryan's modification[3] of Crone's solution and replenishments made mostly with sterile distilled water and occasionally the original kind of solution.

It soon became apparent that the plants inoculated with bacteria from abnormal plants were of a lighter green color than those treated with organisms from the normal plants. This condition intensified with a corresponding variation in vigor until they were harvested May 16, 1929. The roots of the normal plants exhibited nodules mostly near the crown. These were considered typical because they somewhat paralleled in appearance and position those of the original roots. They were large, white, and of good shape, while, on the other hand, nodules on the abnormal plant roots matched those of the abnormal field samples fairly well in that they were scattered over the roots, small, somewhat water-soaked in appearance and often lacking in the characteristic shape. Each individual culture of Austrian winter pea organism was represented in this experiment by three jars and the above-mentioned conditions were consistently noted in each jar throughout the series.

While no uninoculated plants of Austrian winter peas were available for comparison, nearby uninoculated purple vetch plants growing under similar conditions indicated that foreign infection was under control.

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[3] BRYAN, O. C. Influence of reaction on nodule formation. Soil Science, 13: 274–285. 1922.

A tabular summary of the observations made on these plants is given below:

Organism	Number of plants	Length in inches*	Total weight in grams* Green	Dry
Normal (1)	17	14–30	94	10.5
Normal (2)	17	15–28		
Normal (3)	16	12–27		
Abnormal (1)	20	13–23	82	9.5
Abnormal (2)	18	10–16		
Abnormal (3)	17	11–17		

*Includes roots.

The plants of each treatment were combined and thoroughly dried in an oven They were then ground and analysed for nitrogen. The normal plants showed 2.77% nitrogen, while the abnormal plants gave 1.89% nitrogen

It is evident, although previous lime treatments may suggest the contrary, that there are no significant differences in acidity in the soil as determined from four samples from this field. While it is quite commonly observed that an excess of water may cause garden peas and related legumes to turn yellow and since it is possible that the land from which these samples came had a high water table, there is no apparent reason for assuming that drainage conditions varied materially in this field and the condition described probably cannot be explained satisfactorily on that basis

Since no crops related to Austrian winter peas from the standpoint of nodule bacteria have been on this soil for at least seven years, the possibility of the presence of a strain which had become parasitic or non-beneficial by close association with plants belonging to the vetch group is rather remote unless it was brought in by flood water It is not beyond the realm of possibility that variation in soil conditions may have been contributory to the delinquency of the bacteria by weakening the plant, thereby upsetting the balance between the two organisms. Without more facts, further speculation as to the probable causes of this condition is idle If a similar condition can be reproduced by inoculation under somewhat similar soil and climatic conditions, it may be possible to trace this trouble more definitely.

DETERMINING THE DATE OF SILKING IN EXPERIMENTS WITH CORN[1]

Marion T. Meyers[2]

The date of silking has been used widely as a criterion of the relative length of season required by different kinds of corn. It also has been used as marking the transition from the vegetative to the fruiting stage. The date of the first silks and the dates on which 1/10, ¼, and ½ of the plants have silked, as well as the actual mean date of silking, and an estimate based on simple observation, have all been used by different investigators to represent the date of silking of a group of plants. Estimates based on simple observation are unsatisfactory because of the personal equation entering into such estimates. The date of the appearance of the first silks frequently is misleading, as the performance of a few plants is used to represent the whole plat and the plants first silking may be abnormal.

The mean date of silking, computed from the dates on which all of the individual plants in the plat have silked, is absolute, but involves considerable labor and expense. The dates on which 1/10, ¼, and ½ of the plants have silked also are satisfactory. Of these, the median date of silking (when ½ of the plants have silked) is least influenced by a few early silking plants. Any record which requires that a fixed proportion of plants shall be in silk, however, necessitates making repeated counts until that proportion is reached. The present note calls attention to a more convenient method of obtaining the median date of silking which appears to be entirely adequate for many experiments.

In connection with the cooperative experiments under conditions of infestation with the European corn borer, it has been necessary to determine the date of silking in many varieties of corn with precision. Dated tags have been attached to the individual plants daily as the silks appeared, as suggested by Culpepper and Magoon.[3] The dates for each plat have been tallied and the mean dates of

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[1] Joint contribution from the Ohio Agricultural Experiment Station, Wooster, Ohio; the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.; and the Ohio State University, Columbus, Ohio. Received for publication November 11, 1929.

[2] Formerly Assistant in Agronomy, Ohio Agricultural Experiment Station, Agent Office of Cereal Crops and Diseases, U. S. Bureau of Plant Industry, and Instructor in Farm Crops, The Ohio State University.

[3] Culpepper, C. W., and Magoon, C. A. Studies of the relative merit of sweet corn varieties for canning purposes and the relation of maturity of corn to the quality of the canned product. Jour. Agr. Res., 28: 403–443. 1924.

silking computed. Two or three per cent of the plants in a plat usually have been barren, never silking, so have been disregarded.

The means and standard deviations for date of silking have been computed from such individual plant records covering a period of three years in a great many crosses and varieties. In very uniform crosses between inbred lines the standard deviation for date of silking of plants within a plat has been as low as 1.5 days, whereas it may be as high as 4 days in some ordinary varieties. A standard deviation of 3 days for plants within a plat may be assumed as approximately modal. Assuming a standard deviation of 3 days, the median date can be estimated with little error from the date on which any given percentage of the plants have silked. Based on this standard deviation, Table 1 gives the corrections to be added to or subtracted from the date on which different percentages of plants are observed in silk to estimate the median date of silking

TABLE 1.—*Corrections for estimating the median date of silking within plats from the date on which the stated percentages of plants were observed in silk.*

Add to or subtract from the date of record	When the percentage of plants silked is	
	Below	Above
1 day	42	58
2 days	29	71
3 days	19	81
4 days	11	89

In practice, the plants which actually have silked are counted when it is estimated by inspection that about 40% have silked The corrections in Table 1 then are applied to estimate the median date of silking. This obviates the need for repeated counts without introducing any personal equation. The assumption of a standard deviation of 3 days is the only one involved. This can introduce little error if the counts are made only when the percentage is close to the median, as the sampling error is small compared to the variability of the entire experiment Counting when extremely high or low percentages of the plants have silked should be avoided to prevent the undue effect of a few aberrant plants.

The median dates of silking were determined by this method for the 68 crosses in Experiment B at Bono, Ohio, in 1928 The plats were 18 3-plant hills long and 2 rows wide. The first row of each plat was used for determining the median date of silking. Fig. 1 shows the correlation (r = 0.88 ± 0.03) between the dates of silking in the two replications of this experiment. Eliminating the effect of differences among the varieties, the partial standard deviation, ${}_{v}\sigma_{d}$, is 2 48 ± 0.14 days. The probable error of the median date of silking of a single plat, holding variety constant, is ± 1.68 days.

		Second replication														
		July			August											
First replication	Date Classes	25 26	27 28	29 30	31 1	2 3	4 5	6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	Totals
August	20 21														1	1
	18 19												1			1
	16 17												2			2
	14 15									2						2
	12 13								2	3	1	1				7
	10 11								5	5	3	2				15
	8 9						2	3	6	8	2					21
	6 7						1	2	1	2						6
	4 5															
	2 3			2	2	1										5
	31 1	1						1								2
July	29 30			2	1											3
	27 28	1	1													2
	25 26				1											1
	Totals	2	1	4	4	1	3	6	14	20	6	3	3		1	68

r_{12} = 0.88 ± 0.03 Combined σ = 5.17 ± 0.21 days.

$v\sigma_d$ = 2.48 ± 0.14 days. PE_s = ± 1.68 days.

FIG. 1.—Correlation between median date of silking in the first and in the second replication of 68 crosses in Experiment B, at Bono, Ohio, in 1928.

In contrast, the mean dates of silking were determined for 50 plats comprising two replications of 25 crosses between inbred lines of field corn grown in Experiment A at Bono, Ohio, in 1928, and the results may be compared with those in Experiment B. The plats were 18 3-plant hills long by 5 rows wide. This experiment was

		Second replication												
		July		August										
First replication	Date Classes	28 29	30 31	1 2	3 4	5 6	7 8	9 10	11 12	13 14	15 16	17 18	19 20	Totals
August	21 22												1	1
	17 18												1	1
	15 16													
	13 14									1				1
	11 12							2	1		1			4
	9 10						2	3	2	1				8
	7 8					2	2	1						5
	5 6					1	1							2
	3 4				1									1
	1 2													
July	30 31													
	28 29	1	1											2
	Totals	1	1		1	3	5	6	3	2	1		2	25

r_{12} = 0.94 ± 0.02 Combined σ = 5.04 ± 0.34 days.

$v\sigma_d$ = 1.75 ± 0.12 days PE_s = ± 1.18 days

FIG. 2.—Cor relation between date of silking in the first and in the second replication of 25 varieties in Experiment A, at Bono, Ohio, in 1928.

adjacent to Experiment B, occupied about an equal area, and was planted on the same day. The arrangement of the crosses was entirely at random in each experiment. All plants in the second row of each plat were tagged for silking date, so that each sample consisted of slightly more than 50 plants, as in Experiment B. Fig. 2 shows the correlation between the mean dates of silking in the first and the second replications ($r = 0.94 \pm 0.02$). Eliminating the effect of variation among the crosses, the partial standard deviation, ${}_{v}\sigma_{d}$, is 1.75 ± 0.12 days. This is larger than that of 0.42 day based on an assumed standard deviation of 3 days for date of silking of individual plants. The excess is largely due to the effect of the soil variation from plat to plat. The probable error for the mean date of silking of a single plat in this experiment, holding variety constant, is ± 1.18 days. This is 30% less than the probable error for the median in Experiment B.

The total variation was about the same in the two experiments, *viz.*, $\sigma = 5.17$ and 5.04. The difference in the probable errors comes about through the lower correlation between replications in Experiment B, based on median dates. Whether this lower correlation was due to the use of medians rather than means in Experiment B, or whether it was a chance difference, is not known. Judging the coefficients of correlation in terms of their probable errors, however, the difference well might be one of chance.

Determining the median date of silking as outlined is easy and convenient. It is strictly quantitative, involving no element of personal estimate, and obviates the necessity of repeating the counts until a specified proportion of the plants are in silk. Finally, its precision is adequate for the purposes of many corn experiments.

NOTE

FRENCHING OF TOBACCO AND LIMING

Valleau and Johnson, in 1927, reported work on frenching of tobacco (Ky. Agr. Exp. Sta. Bul. 281). In this work Turkish tobacco was grown in the greenhouse in small volumes of a forest soil. Frenching and the yellowing commonly recognized as resulting from nitrogen starvation usually occurred nearly simultaneously. The frenched condition of these plants was overcome by addition of a number of nitrogenous materials. They concluded that there appeared to be a definite relation between the available nitrogen in the soil and frenching in the plant. They referred to the fact, however, that in the field frenching usually occurred in the absence of the nitrogen starved appearance.

They reported the lime-frenching relationship on the Campbellsville soil experiment field in 1927 when much frenching occurred on the limed plats and none on the unlimed plats. They also reported one other instance where lime apparently brought about frenching. In their greenhouse work with the forest soil, large applications of calcium oxide prevented frenching, which indicated to them that lime affected frenching primarily through its effect on nitrogen availability.

Since the above publication, additional observations of the lime-frenching relationship have been made. Considerable frenching developed again at the Campbellsville field on the limed plats in 1928 and in 1929. Considerable frenching also developed in 1928 on the limed plats at the Greenville and Hopkinsville fields and a little at the Mayfield field. On none of these fields has frenching been observed on unlimed plats, except on one plat at the Hopkinsville field located next to a macadam road, which undoubtedly has received more or less wind-blown lime dust from the road. Details as to soils, cropping, and fertilizer treatments on these fields are given in Bulletin 272 of the Kentucky Experiment Station. When it was realized that the lime-frenching relationship might become of considerable importance in the field, this problem was turned over to the senior writer for further study.

In his studies, Turkish tobacco grown in the greenhouse in ½-gallon pots in soils from the Campbellsville and Greenville fields has invariably frenched in the field limed soils but never in the unlimed soils. In 1929, very severe frenching developed in fields in Laurel County, on soil similar to the Fariston soil experiment field, on which considerable pulverized limestone had been used in the near past, in addition to which, on several of the fields, very fine limestone had been drilled along the row before setting.

In correspondence, H. G. M. Jacobson, of the Connecticut Agricultural Experiment Station, states that in greenhouse work with Turkish tobacco, frenching occurred on limed soils but not on unlimed soils. L. G Willis, of the North Carolina Experiment Station, also in correspondence, states that members of the Department of Agronomy of that institution have found that "at the Edgecombe Branch Station, Rocky Mount, N. C., frenching of tobacco has been almost strictly confined to the limed plots of the experimental field."

It seems evident that liming favors frenching on at least some soils. However, considerable tobacco is grown on limed land in Kentucky and so far very few reports of difficulty with frenching on this land have come to the attention of the experiment station. Furthermore, frenching seems to be rare in tobacco grown on hillsides in certain parts of the bluegrass region of Kentucky where the soil contains much calcareous material.

In the later greenhouse work, determinations of nitrates have shown, at times, as much as 100 pounds of nitrate nitrogen per 2,000,000 pounds of dry soil in the limed soils when frenching occurred. In the unlimed soils, where frenching did not occur, none or a trace only of nitrates was found during later stages of growth of the plants.

The determinations made show that nitrates reached a high level in the soils within a few weeks after potting and adding water, probably influenced by the air-dry condition the soils had been in during storage, and that in both the limed and unlimed soils the amount later decreased, probably largely in proportion to use by the plants It now appears less probable that frenching of tobacco is directly caused by a deficient supply of nitrogen.

So far, it has not been possible to develop frenching in Turkish tobacco in sand or water cultures with deficient supplies of nitrogen, phosphorus, potassium, magnesium, or iron with the pH of the culture solution between 5 and 6. The failure of frenching to develop in these sand cultures directed attention to the fact that Valleau and Johnson used considerable lime in their sand culture work where frenching occurred, though for another purpose Valleau then called attention to the fact that the forest soil used in most of their work had substantially the pH value of the limed experiment field soils, the value as reported in their publication being pH 6.8. We have no evidence that deficiency of manganese is a factor in frenching. Potassium fertilizers have been observed to give some control in the field. Further work is in progress on the nature and control of frenching.—P. E. KARRAKER and W. D. VALLEAU, *Kentucky Agricultural Experiment Station.*

PATRICK BEVERIDGE KENNEDY

The following resolution on the death of Dr. P. B. Kennedy, Professor of Agronomy in the California College of Agriculture and Agrostologist in the Experiment Station, and for many years an active member of the American Society of Agronomy, was drawn up by a committee composed of A. C. Alvarez, G W Hendry, and G. D. Louderback.

The death of Patrick Beveridge Kennedy on January eighteenth, 1930, brought to a close the career of a man who served the University of California faithfully and well. Born in the country near Glasgow, Scotland, and descended from a line of distinguished naturalists, he began life endowed with a cultural heritage accorded to but few. From early youth, agriculture, botany and horticulture were the things which lay next his heart, and in these subjects his formal education was begun in Scotland, continued in England and Canada, and completed in the United States, where he took his Ph.D. degree in botany at Cornell University in 1899. Following fourteen years of productive service, as Professor of Botany and Horticulture in the University of Nevada, he accepted a call to the University of California in 1914. Imbued with lofty ideals of research and a rare love and understanding of the plant materials with which he worked, he attracted to his laboratory in ever increasing numbers graduate students who found there unequaled opportunities for study in the field of agrostology.

Early in his career he undertook the difficult task of the taxonomic revision of the genus Trifolium, and this became the subject of many of his best known published contributions. A few days before his death he was working on the completion of the section of this study treating of the bladder clovers. He was the author of numerous monographs on grasses, saltbushes, forage plants, alpine plants, and ecology, and published more than one hundred papers upon these and allied subjects. As one of the leading agrostologists in the United States, his advice was widely sought and highly valued.

In the face of conflicting demands he consistently maintained a fine balance between the scientific and the applied phases of his subject, and was ever alert for an opportunity to advance agricultural practices. By the introduction of Harding grass, Kikuyu grass, Rhodes grass, bulbous bluegrass, and other forage plants, he left the stock ranges of California better than he found them. He instituted studies in the eradication of wild morning-glory which provide the foundation for the solution of one of the most vexing agricultural problems of California. The herbaria of economic plants, weeds, and seeds which he assembled are unequalled in California. He was known as an authority upon turfs and the wealth of exact knowledge which he brought to bear upon practical turf problems was a revelation to commercial seedsmen, practical gardeners and the greens committees of country clubs, who continually sought his advice.

Although burdened with domestic cares in his later years his cheerfulness and youthful spirit never failed. His willingness to help all who sought his counsel endeared him to those who knew him. His many loyal friends afforded him one of his greatest pleasures.

In the world at large Patrick Beveridge Kennedy will be remembered as a scientist, but those who were privileged to work and to play with him will remember him as a genial and modest personality and a lovable human being.

AGRONOMIC AFFAIRS

THE CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARD

About two years ago the Chilean Nitrate of Soda Educational Bureau of New York made available an annual appropriation of $5,000 to be distributed in the form of one or more prizes for outstanding research in this country and Canada on nitrogen in its relation to soil processes and plant growth. The above sum has been placed in the hands of the American Society of Agronomy, the award being administered by a special committee of the Society.

The first awards were made in 1928. The committee held then that it was advisable to select older investigators whose previous work in advancing knowledge of nitrogen in relation to plant growth has been beyond question. Dr. J. G. Lipman, Director of the New Jersey Agricultural Experiment Station; Dr. T. L. Lyon, Chief of the Agronomy Department, Cornell University; Dr. E. B. Fred, Division of Agricultural Bacteriology, University of Wisconsin; and Dr. F. T. Shutt, Dominion Chemist, Ottawa, Canada, were those selected. In connection with the announcement of the selections for 1928, the Committee suggested that subsequently it would be appropriate to consider and perhaps even to give preference to those younger investigators who have made recent contributions to the subject.

The second award, announced at the 1929 meeting of the Society, was divided among three investigators, namely, Professor C. A. Mooers, Director of the Tennessee Agricultural Experiment Station; Dr. P. L. Gainey, Soil Bacteriologist of the Kansas Agricultural Experiment Station; and Dr. S. A. Waksman, Microbiologist of the New Jersey Agricultural Experiment Station.

In order to make clear the nature of the investigations that will be considered for the award in 1930, the committee feels that it is desirable to publish a brief statement at this time.

Investigations will be considered which deal with the physical, chemical, or microbiological transformation of both organic and inorganic nitrogen in the soil, the absorption and utilization of nitrogen by plants, and nitrogen fertilizer in any of its aspects. The committee will give particular attention to those contributions which have been published within the past year or two. Investigations of longer standing will also be considered, provided the authors are still actively engaged in the work.

Investigations dealing with any phase of nitrogen in relation to soils and crops may be called to the attention of the committee either by an author himself or by any one else. The award, which may be made either to one or more investigators, will be recommended to the Society, according to the judgment of the committee.

The committee takes this opportunity to solicit nominations of candidates for the 1930 award. The nominations should be made in writing and may be addressed to any member of the committee. Although it may be difficult to select the "most" outstanding contribution to such a complex subject as nitrogen in its relation to soils and plants, the committee hopes that it will at least be able to select one or more investigators who have made a notable contribution to the scientific understanding of the rôle of nitrogen in soils and plants. It is expected that the award will be used in such a way as to lead to still higher scientific activity.

The award is open to investigators irrespective of their connection with the American Society of Agronomy. The investigation may have been made at a university, state experiment station, government institution, or privately.

Chilean Nitrate of Soda Nitrogen Research Award Committee,

R. W. THATCHER R. I. THROCKMORTON
C. B. WILLIAMS R. BRADFIELD
W. P. KELLEY S. A. WAKSMAN, *Chairman*

MEETING OF SOUTHWESTERN AGRONOMISTS

The winter meeting of the Southwestern agronomists, comprising representatives from Arkansas, Louisiana, Oklahoma, and Texas and workers in the various phases of the fertilizer industry, was held at Jackson, Mississippi, February 4. Agronomists from each of the four states represented discussed at length the results of their fertilizer experimental work. These reports were followed by a round-table discussion of some of the leading problems of common interest to the Southwest.

NEWS ITEMS

Dr. H. H. Love of Cornell University gave the first series of lectures under the Frank Azor Spragg Memorial Fund at Michigan State College, January 27-31. This memorial fund is in honor of Professor F. A. Spragg who was one of the first men employed by an agricultural experiment station to devote his entire time to plant breeding. He began his work with the Michigan Experiment Station in 1906 and continued with that institution until his death in 1924.

President Kelly has appointed Dr. H. J. Harper of the Oklahoma Experiment Station to the Committee on Fertilizers, vice Professor George Roberts who asked to be relieved from duty on the Committee. Also, Professor R. M. Salter of Ohio State University has been appointed to the Committee on Fertilizer Distributing Machinery.

Dr. F. R. Immer of the Division of Agronomy and Plant Genetics, University of Minnesota, has been granted a fellowship for a year's study in Europe under the auspices of the National Research Council out of funds provided by the Rockefeller Foundation Dr. Immer will devote his attention primarily to the use of statistical methods in the interpretation of the results of genetic and plant research.

In a recent number of *Science* is noted the presentation on February 25 to Dr. C. F. Marbut, Chief of the Soil Survey of the U. S. Dept. of Agriculture, of the Cullum Geographical medal by the American Geographical Society. The award was made in recognition of Dr. Marbut's studies and classification of the soils of Europe, Africa, and North and South America.

Dr. Collins Veatch, who received his Ph.D. in Agronomy at the University of Illinois in June 1929, is now employed as Agronomist by the Corn Products Company, and is located on the island of Santo Domingo, where this company has large land holdings.

Karl B. Daniloff, formerly of Washington State College, has been appointed Assistant in Soil Fertility at the University of Illinois, his special work being in research pertaining to rock phosphate.

F. M. Willhite has resigned his position as First Assistant in Soil Fertility at the University of Illinois to become adviser in soil fertility matters for the Aetna Life Insurance Company. The land under his supervision lies mainly in Indiana and Ohio.

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VIGOR IN SOYBEANS AS AFFECTED BY HYBRIDITY[1]

COLLINS VEATCH[2]

INTRODUCTION

Soybean improvement in this country has been practically limited to the introduction of strains from the Orient and the selection of pure lines from the ordinary heterogeneous varieties Improvement by hybridization has been little used for this crop Practically all of the studies of hybrids have been made for genetic purposes.

The increased vigor of many hybrid plants has been observed ever since the beginning of plant breeding studies. Many of the recent papers on hybrid vigor in plants have been based on data secured from crosses between inbred lines of corn. Other papers have reported the occurrence of hybrid vigor in such self-fertilized crop plants as tobacco, tomatoes, wheat, oats, peas, and beans Wentz and Stewart (8)[3] found a marked increase in height and yield of soybean hybrids when compared with plants of the parental varieties. Thus, it has been well demonstrated that the phenomenon of hybrid vigor is not confined to crosses between selfed lines of ordinarily cross-fertilized species.

The possibility of securing higher yielding strains of soybeans through hybridization and selection made it seem desirable to collect records on various characteristics of plant development as affected by hybridity in the first and second hybrid generations when different varieties were crossed. The purpose of this paper is to present data showing the effect of hybridity on plant development in the soybean (*Soja max* Piper).

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[1] Contribution from the Division of Plant Breeding, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication October 14, 1929.

[2] Formerly, graduate student in Plant Breeding; now with the Compañia Agricola, S. F. de Macoris, Dominican Republic. The author wishes to express his appreciation of the suggestions given by Doctor C. M. Woodworth during the progress of this study and also for the encouragement and assistance in the preparation of the manuscript.

[3] Reference by number is to "Literature Cited," p. 310.

MATERIAL

The 16 varieties or strains of soybeans used in the crosses were furnished by Doctor C. M. Woodworth and have been carried on as pedigree strains from single plants. Two of the strains were designated by abbreviations of the U. S. Plant Introduction numbers. The Black Coat strain was a black-seeded green cotyledon type of unknown origin. The Chimera strain originated from a chimera soybean plant. One side of this plant was purple-stemmed and bore purple flowers, while the other side was green-stemmed and bore white flowers. The Chimera strain came from the green-stemmed, white-flowered part of the plant. The other strains used as parents were selected from standard varieties.

METHODS

GROWING SOYBEANS IN THE GREENHOUSE

There are many advantages in growing soybeans in the greenhouse for artificial cross-pollination. In the greenhouse the planting dates may be varied so that the early- and late-maturing varieties will flower at approximately the same time. The date of planting may be varied in the field, of course, but not so readily as in the greenhouse. It is often difficult to emasculate and pollinate flowers on small plants in the field, since one must get on the ground in a cramped position, whereas in the greenhouse the potted plants may be moved about and placed to suit one's convenience. However, in the greenhouse, it was necessary to expose the plants to artificial light at night and on cloudy days, especially during the early growth period, to increase the vegetative development and to secure good vigorous plants. Under these conditions, the dwarf types of soybeans produced larger plants and flowers in the greenhouse than in the field.

The parent strains grown in the greenhouse for crossing were germinated in sand. Three of the best plants of each strain were transplanted to gallon jars filled with a mixture of 2 parts brown silt loam, 1 part well-rotted manure, and 1 part sand. Inoculation was secured by the use of soil from a field where soybeans had recently been grown or by the use of pure cultures of *Bacillus radicicola.*

HYBRIDIZATION

The small size of the soybean flower makes artificial cross-pollination difficult. In emasculating the flower, the corolla was removed with a pair of small pointed forceps and then the 10 anthers were removed with a dissecting needle. While removing the anthers, care was taken to keep from breaking them open and thus self-pollinating the flower, and also to keep from injuring the ovary. After emasculating the flower, the dissecting needle was cleaned with alcohol and then used to apply the desired pollen to the stigma. After cross-pollinating, a small tag bearing a record of the cross was placed on the stem just below the flower. A leaf which remained attached to the plant was then pinned around the cross-pollinated flower to protect it, and to reduce evaporation from the mutilated parts. Only about 10 to 15% of the artificial cross-pollinations attempted were successful.

The possibility of self-pollinating the flower during the process of emasculation makes it necessary to test the hybridity of all seeds produced from such flowers by growing the F_1 generation, or the F_2, if the paternal parent does not bring in any dominant characters which will be manifest in the F_1. The hybridity of all hybrids reported in this paper was definitely proved by the dominance or segregation of certain characters, such as flower or pubescence color or seed characteristics.

METHODS OF PLANTING AND COMPARING HYBRIDS WITH THEIR PARENTAL VARIETIES

During the winter of 1926–27, nine successful crosses were made in the greenhouse. These hybrids were grown in comparison with plants of the parental strains in the field in 1927. The hybrid beans and beans from the parental plants were planted in small paper pots in the greenhouse May 17 and transplanted to the field May 31 and June 1. The plants were spaced 1 foot apart in rows 32 feet long. Two plants of one parental strain were set out, then the hybrid and two plants of the other parental strain, and so on.

Records were taken on the color and the date of appearance of the first flowers. When mature, the plants were pulled, tagged, placed in gunny sacks, and hung in the screen shed. After drying, the plants were threshed by hand and plant records taken on number of shattered seeds, internodes, pods and seeds, total branch length, height, weight, and color of pod, seed-coat, hilum, and cotyledons. The record on number of shattered seeds was used to correct the records on plant weight, seed weight, and number of seeds.

During the summer of 1927 several crosses were made in the field. Seven of these crosses were grown in comparison with the parental strains in the field in 1928. These hybrids were grown in a manner similar to that previously described, except that they were planted directly in the field on May 26. At harvest time the plants were pulled, tied separately, tagged, and hung in the drying shed. Similar records were taken as on the hybrids grown in 1927.

The best plant of each parental strain, selected on the basis of seed weight, was used in making comparisons with the hybrids.

THE F_2 POPULATIONS

The F_2 populations were grown in the field in 1928. The seeds were planted 6 inches apart, in rows 16 feet long and 24 inches apart. A row of one parental strain was planted, then an F_2 row, and a row of the other parental strain followed by another F_2 row, and so on, planting as many rows as the supply of F_2 seed would permit. Where the hybridity of the F_1 plant was in doubt, only five F_2 rows were planted. The seeds of the parental strains came from the plants that were compared with the F_1 plants the previous year. Tags bearing the plant number with the color and date of appearance of the first flowers were placed on the plants of the F_2 populations and parental strains. At harvest time the plants of each row were pulled, tied in a bundle, and hung in the drying shed.

Two men worked together in threshing the plants and recording data. One man measured the length of the plant from the ground line to the tip, recording on the envelope the length, number of shattered seeds, the row and plant numbers, and the date of harvest. The other man threshed the plants on the bar-cylinder plant thresher designed by Mumm and Winter (5), and placed the seed in the proper envelopes. After threshing, further records were taken on the weight of seeds, number of seeds, and color of seedcoat, hilum, and cotyledons.

The F_2 results reported in this paper are limited to seed number, seed weight, plant height, and number of days from planting to flowering.

Several of the populations supposed to be hybrid were discarded because they failed to segregate for the characters in which the parents differed. Others were eliminated, even though they segregated as expected, because they were frosted and failed to reach maturity. Hence, data on only four F_2 populations will be presented.

TABLE I.—*Percentage increases or decreases of the hybrids over the average of their parents for the various plant characters studied.*

Hybrids	No. hybrids averaged	Yield	No. seeds	Ave. seed weight	Abortive seeds	No pods per plant	No. seeds per pod	Plant weight	Straw-grain ratio	Plant height	Total stem and branch length	No. nodes	Ave. inter-node length	Days to flowering
Tall Manchu x A. K. 2.	1	58.64	40.22	12.21	75.52	33.53	5.09	58.24	0.00	32.92	—	—	—	5.49
Early Manchu x Morse. .	2	95.91	106.50	—4.40	—38.11	73.88	17.74	119.75	—19.14	30.21	—	—	—	27.12
Early Manchu x A. K. 3.	1	—2.57	20.14	—19.11	15.64	8.16	10 78	1.05	—6.65	4.05	—	—	—	6.38
Morse x Wea	1	—7.38	—29.86	32.43	36.15	—19.36	—13.33	—10.08	3.24	—2.70	—	—	—	22.31
Morse x Peking. . .	3	36.30	21.35	0.00	—39.02	13.49	4.95	—45.13	—10.19	—	36.11	15.26	13.35	7.59
Morse x Virginia. .	2	—1.17	—4.63	—0.74	2.63	—11.65	7.94	0.00	—1.27	31.78	—	—	—	9.33
Peking x Dunfield. .	2	54.18	42.97	—3.67	56.85	54.72	—4 74	69.57	—15.12	23.47	53.89	54.34	—6.70	2.78
Chimera x 345	2	44.35	22.39	8.50	83.13	37.16	—6.36	50.65	—7.88	5.38	53.20	26.67	35.20	12.50
A. K. 114 x 394.	1	32.11	20.86	8.24	17.22	10.76	9.49	27.01	4.77	4.13	—	—	—	5.75
Wea x Virginia. .	2	33.02	28.44	3.70	—	18.62	7.66	28.21	8.18	6.74	9.71	0.00	11.87	—
Manchu Dwarf x Wea. . . .	2	63.96	69.57	—6.47	—	51.76	11.05	76.47	—13.72	48.08	89.63	50.91	31.58	8.16
Dunfield x Elton.	3	15.08	10.92	2.05	—	26.61	—14.06	12.50	3.01	6.85	28.40	29 11	2.19	1.72
Elton x A. K. 114.	2	7.12	11.22	—2.53	—	9.68	1.44	—1.39	16.25	9 59	—12.86	0.00	—10.02	10.20
A. K. 114 x Wea.	4	14.58	9.56	4.34	—	0.75	4.83	4.65	17.01	8.64	17.98	18.18	—3.72	7.27
Elton x 394.	2	85.80	83.33	1.43	—	62.34	12.76	78.05	6.55	17.39	42.86	45.45	3.28	—11.32
Black Coat x Tall Manchu	2	37.65	23.79	12.78	—	21.88	0.00	25.32	18.08	—1.30	25.63	12.50	11.13	11.54
Average increase, %	-	35.47	29.80	2.33	15.76	24.79	3.09	36.28	0.99	15.04	32.76	24.80	7.44	7.92

TABLE 2.—*Percentage increases or decreases of the hybrids over their higher parent for the various plant characters studied.*

Hybrids	No. hybrids averaged	Yield	No. seeds	Ave. seed weight	Abortive seeds	No. pods per plant	No. seeds per pod	Plant weight	Straw-grain ratio	Plant height	Total stem and branch length	No. nodes	Ave. inter-node length	Days to flowering
Tall Manchu x A. K. 2.	1	52.87	27.41	5.76	73.12	24.86	1.79	48.45	—5.46	17.58	——	——	——	—2.08
Early Manchu x Morse..	2	71.53	81.42	—5.00	—55.28	62.94	10.05	106.98	—30.26	6.84	——	——	——	1.35
Early Manchu x A. K. 3.	1	—5.24	19.32	—20.63	—13.75	2.58	2.25	0.00	—9.74	1.12	——	——	——	6.00
Morse x Wea	1	—23.70	—32.88	13.29	24.23	—26.21	—17.37	—28.40	—5.02	—23.08	——	——	——	0.00
Morse x Peking....	3	23.95	—6.26	—26.32	—50.80	—16.86	—3.54	45.13	—24.22	——	17.93	—11.15	—1.32	1.19
Morse x Virginia...	2	—4.16	—22.55	—18.18	—5.44	—28.06	7.94	—3.39	—1.39	16.44	——	——	——	7.89
Peking x Dunfield..	2	32.90	32.82	—26.57	—3.25	21.93	—14.62	62.50	—30.42	23.47	41.21	18.67	—23.27	—11.90
Chimera x 345	2	—3.36	—22.09	—2.35	40.86	—10.57	—12.43	0.87	—7.88	5.38	—4.42	—3.62	0.20	12.50
A. K. 114 x 394.......	1	27.23	12.57	—2.65	—13.97	8.02	4.17	13.56	—14.74	—25.00	——	——	——	4.55
Wea x Virginia...	2	13.49	23.80	—14.50	——	9.55	2.58	25.00	—17.06	—8.65	—13.86	—6.45	—7.26	——
Manchu Dwarf x Wea....	2	62.67	47.57	—18.88	——	35.79	8.21	76.47	—12.25	20.31	32.91	29.69	2.46	—1.85
Dunfield x Elton.....	3	—4.70	—11.11	—2.61	——	9.79	—20.67	—11.96	—16.53	—10.34	12.14	27.50	—10.64	0.00
Elton x 114.	2	—12.89	—8.79	—3.14	——	—5.56	—4.07	—19.32	14.87	—13.75	—32.92	—13.33	—21.71	3.85
114 x Wea..	4	1.58	2.41	—1.36	——	—11.26	—1.36	—15.09	—9.76	4.76	3.23	1.11	—6.34	5.36
Elton x 394.	2	66.38	71.88	—2.74	——	45.35	7.28	52.08	—10.60	1.89	—0.40	29.03	—22.22	—18.97
Black Coat x Tall Manchu	2	28.65	17.25	11.11	——	18.18	—8.26	19.28	15.56	—1.30	17.86	5.88	10.69	0.00
Average increase, %	–	19.55	13.33	—8.03	—8.60	7.57	—2.93	22 30	—11.10	2.07	7.22	8.02	—7.92	0.64

VIGOR AS AFFECTED BY HYBRIDITY IN THE F_1 GENERATION

YIELD

In agronomic investigations yield is of major interest. To secure a high yield per unit area of soil there must be a good yield per plant and proper distribution of the plants over the area. Yield, or weight of seed produced per plant, has been used as one of the principal criteria of hybrid vigor in crop plants.

The increases or decreases of the hybrids, as compared with their parental averages and their better parents, are given in Tables 1 and 2, respectively.

The average yield of the parents was 38.41 grams of seed, while the average of all the hybrids was 50.81 grams. The highest yielding plant studied was one of the Early Manchu x Morse hybrids which yielded 83.28 grams. As a rule, the hybrids yielded better than the average of their parental strains, or even than their better parental strain. Only 3 of the crosses yielded less than the parental average (Table 1), while 10 exceeded either parental strain in yield (Table 2). In fact, the hybrids yielded an average of 19.55% more than their better parental strains

The correlation coefficients given in Table 3 show a correlation of 0.409 ± .103 between yield of the hybrids and yield of the higher parental strains, and 0.514 ± .091 when yield of the hybrid was correlated with the average parental yield.

TABLE 3.—*F_1 hybrids correlated with the parental plants for the characters indicated.*

Character	Higher parent	Parental average	Parental difference	Yield of hybrids
Days to flowering....	0.816±.040	0.445±.096	0.375±.102	0.344±.105
Yield....	0.409±.103	0.514±.091	−0.038±.123	————
Seed number........ ...	0.600±.076	0.643±.070	0.284±.110	0.841±.035
Plant height.......... .	0.702±.062	0.871±.030	0.207±.118	0.347±.108
Number of pods...... .	0.766±.049	0.893±.024	0.622±.073	0.737±.054
Straw-grain ratio.......	0.522±.087	0.645±.070	−0.007±.119	0.047±.119
Average seed weight.....	0.441±.096	0.723±.057	————	−0.056±.119
Plant weight..	0.345±.105	0.852±.033	————	0.911±.020
Total stem and branch length..............	————	0.342±.132	————	0.760±.059
Number of nodes.......	————	————	————	0.797±.051
Average internode length.	————	————	————	0.357±.123

NUMBER OF SEEDS PER PLANT

The seed yield is obviously dependent to a large extent upon the number of seeds produced per plant. The data in the second column of Tables 1 and 2 indicate that there is a tendency for the hybrids to produce more seeds than the average of the parents or even than the higher parent.

A comparison of the first and second columns in Table 1 shows that in 12 out of the 16 crosses the percentage increase in number of seeds produced is lower than the percentage increase in yield. This would lead one to suspect that in these cases the average seed weight of the hybrid plants was higher than the parental average. This supposition is justified by the adjoining column showing the increases in average seed weight. The highest number of seeds produced was 694 by one of the Peking x Dunfield hybrids. The Peking variety was rather consistent in producing a large number of seeds per plant.

The correlation between number of seeds produced by the hybrid and the better parent was 0.600 ± .076 and the correlation with the parental average was 0 643 ± .07 (Table 3).

AVERAGE SEED WEIGHT

Other things being equal, the yield of a plant will be determined by the average seed weight; that is, the higher the average seed weight, the higher the yield of the plant.

The average seed weight was calculated by dividing the total seed weight by the number of seeds per plant. As shown in the third column of Table 1, there was an increase in the average seed weight of the hybrids over the average of their parents in nine of the crosses, while in only three of the hybrids was there an increase over the heavier seeded parental type (Table 2) In the case of the Morse x Wea cross, the increased average seed weight compensated, at least partially, for the low number of seed produced.

There was a correlation between the average seed weight of the hybrid and that of the higher parent of 0.441 ± .096 and between the hybrid and the average of the parents of 0.723 ± .057 (Table 3).

PERCENTAGE OF ABORTIVE SEEDS

The percentage of abortive seeds, as recorded in the fourth column of Tables 1 and 2, was calculated as follows:

$$\frac{\text{total number of seeds—number of normally developed seeds}}{\text{total number of seeds}} \frac{100}{1} = \text{percentage abortive seeds}$$

The records on the hybrids grown in 1928 were not taken in such a way that the total number of seeds could be determined.

There was considerable variation in abortiveness among the parental strains, as well as among the hybrids. Among the parental strains the abortiveness varied from 2.45 to 25.95%, while among the hybrids the abortiveness ranged from 7.08 to 24.93%.

There is apparently no definite relationship between the abortiveness of the hybrids and that of the parental strains. In the case of the Tall Manchu x A. K. 2 hybrid there was an abortiveness of 8.78% in the Tall Manchu parent and 8.58% in the A. K. 2 parent, while there was 15.20% abortiveness in the hybrid. In the case of one of the Morse x Peking hybrids there was an abortiveness in the parental plants of 18.25 and 25.95%, respectively, while in the hybrid the abortiveness was only 7.21%. In other cases the abortiveness in the hybrid was more or less intermediate between that of the parents.

NUMBER OF PODS PER PLANT

The soybean produces from one to four seeds per pod. If the production of seed is to be high, a plant must obviously produce either a large number of pods or a large proportion of three- and four-seeded pods.

The hybrids that exceeded the average of the parents in number of seeds produced per plant also exceeded the average of the parents in the number of pods produced. The highest producing hybrid was one of the Peking x Dunfield hybrids which produced 357 pods. The Peking parent strain was high in number of pods produced as well as in number of seeds per plant, one plant producing 387 pods.

The correlation between the number of pods produced by the hybrid and the average of the parents was 0.893 ± .024 (Table 3), indicating that the number of pods was intermediate in expression in the hybrids.

AVERAGE NUMBER OF SEEDS PER POD

If the number of pods and size of seed were constant, the yield per plant would be dependent upon the number of seeds produced per pod. An increase in the number of good seeds produced per pod would tend to increase plant production.

The average number of seeds per pod was calculated by dividing the number of seeds per plant by the number of pods. There was no great variation in the number of seeds produced per pod. The average for the hybrids was a trifle over two seeds per pod which was a slight increase over the average of the parental strains and a slight decrease below the average of the better parental plants.

The highest average number of seeds produced per pod (2.44) was produced by one of the Wea plants. One of the Wea x Virginia hybrids produced 2.40 seeds per pod, and one of the A. K. 114 x Wea hybrids produced 2.41 seeds per pod.

PLANT WEIGHT

The plant weight includes the air-dry weight, in grams, of the main stem, root, branches, pods, and seeds. The seventh column of Table 1 shows that in two of the crosses the hybrids were lighter in plant weight than the parental average. However, the hybrids were heavier than either parent in 10 out of the 16 crosses. In comparison with the better parental types, the Early Manchu x Morse was the best with an increase of 106.98% over the better parental type, while the Morse x Wea was the poorest with a decrease of 28.40% below the heavier parent. The average increase in the hybrids over their heavier parental types of 22.30% indicates that there was considerable hybrid vigor, as expressed by plant weight, in most of the crosses.

STRAW-GRAIN RATIO

The straw-grain ratio was calculated by the following formula:

$$\frac{\text{seed weight}}{\text{plant weight} - \text{seed weight}} = \text{straw-grain ratio.} \qquad 2$$

Thus, a high ratio indicates that a high proportion of the plant weight was due to the weight of the seed.

The percentage increase or decrease of the hybrids in comparison with the average of the parents and the higher parent are given in the eighth column of Tables 1 and 2, respectively. Eight of the 16 crosses showed a higher straw-grain ratio than the parental average, while only 2 were higher than the better parental plants.

There was a correlation of 0.645 ± .070 between the straw-grain ratios of the hybrids and the parental average (Table 3).

PLANT HEIGHT

Plant height is a good criterion of hybrid vigor. The height of a plant is determined by the number of nodes and length of internodes. For instance, the height of a plant may be increased by increasing the number of nodes or the length of internodes. Keeble and Pellew (4) have shown this in crosses between a thick-stemmed pea with short internodes and a thin-stemmed pea with long internodes. The increased height of the hybrid was accounted for on the basis of the dominance of factors for number and length of internodes brought together in the hybrids. In the case of a plant that segregated for a large luxuriant late type and a short bushy early type of soybean, Woodworth (10) found the tall late type to be dominant. Wentz and Stewart (8) have presented data showing a marked increase in height of certain soybean hybrids over the parental average.

With two exceptions, the hybrids of the crosses included in this study were taller than the parental average. Where there was a marked difference in the height of the parental types, as in the Early Manchu x Morse, Chimera x 345, and Manchu Dwarf x Wea crosses, the hybrids exceeded the taller parents in height (Table 2).

TOTAL STEM AND BRANCH LENGTH

A high total stem and branch length leads to the possible production of a high number of seeds per plant, especially if this length is accompanied by a high number of nodes, since the flowers originate at the nodes. Of the 10 crosses on which total stem and branch length records were collected, only 1 was below the parental average (Table 1). On the whole, there was an average increase of 7.22% in the total stem and branch length of the hybrids over the better parents (Table 2).

NUMBER OF NODES PER PLANT

In the soybean the flowers originate at the nodes. Therefore, it would be expected that as the number of nodes per plant increases, the production of pods and seeds would increase. In this connection it is interesting to note that there is a correlation of 0.797 ± .051 between the number of nodes and yield in the hybrids (Table 3).

As shown in Table 1, there were no crosses with fewer nodes than the parental average, although in two of the crosses the number of nodes in the hybrids equalled the average of the parents. On the other hand, 6 of the 10 crosses produced more nodes than either parental type (Table 2).

AVERAGE INTERNODE LENGTH

As shown above, there was an increase in total stem and branch length for the hybrids over the parental types. Therefore, it seemed desirable to determine whether this increase was due to the production of more nodes or to longer internodes.

The average internode length was calculated by dividing the total stem and branch length by the number of nodes. The average increase of the hybrids over the average of their parental strains was 7.44%, while there was an average decrease of 7.92% below the parental types with the longer average internodes. Therefore, since there was an average increase over the better parents in total stem and branch length, and in number of nodes per plant, one may assume that as a rule in these hybrids the total stem and branch length was increased more by increasing the number of nodes than by increasing the internode length.

DAYS FROM PLANTING TO FLOWERING

Most investigators, according to Jones (3), have found that "hybridity tends to hasten time of maturity as well as to increase size." In the case of a Black Eyebrow by a dominant glabrous soybean cross, Owen (6) found the earliness of the Black Eyebrow to be dominant. On the other hand, Woodworth (10) found late maturity to be dominant in the progeny of a plant that segregated for tall late and short early plants.

The results of the crosses studied here tend to confirm Woodworth's results. The Elton x 394 cross was the only one in which the hybrids flowered earlier than the average of the parents. In the other crosses involving the Elton strain or the 394 strain, the hybrids were as late or later flowering than either parental strain. Out of 15 crosses, 4 flowered earlier than the late parent and 3 flowered on the same day. The above evidence, along with the correlation of 0.816 ± .040 between the hybrids and the late parental plants, indicates that late flowering was dominant in these crosses.

SUMMARY OF THE F_1 RESULTS

The graph in Fig. 1 gives a rather interesting summary of the average percentage increases of the hybrids over the average of their parents and over their better parental strains. The solid line showing the average percentage increase of the hybrids over their parental average indicates that there was an increase in every character studied. However, when the hybrids were compared with the better parents they were, on the whole, exceeded in average seed weight, number of seeds per pod, straw-grain ratio, and average internode length. This figure indicates that the best criteria of hybrid vigor in soybeans for these hybrids are seed weight, seed number, pod number, plant weight, plant height, total stem and branch length, and number of nodes.

The simple correlations given in Table 3 show some interesting relationships. The number of days from planting to flowering for the hybrids gives a coefficient of 0.816 ± .040 when correlated with the later parents. In the case of all other characters where correlations are given between the hybrids and the parental average, and between the hybrids and the better parent, the correlation is higher with the average of the parents. Yield or seed weight in the hybrids gives very significant coefficients when correlated with seed number, number of pods, plant weight, total stem and branch length, and number of nodes.

VIGOR AS AFFECTED BY HYBRIDITY IN THE F_2 GENERATION

Comparisons of the parental and F_2 populations were made on the basis of the mean, the range, and the variability as measured by Weinberg's (7) formula. This formula for measuring the variability of a population is as follows:

$$W = \frac{\sigma\sqrt{Mm - Mo}}{\sqrt{(Ma - Mo)}\ (Mm - Ma)},$$ where W = measure of variability, Mm = maximum variate, Mo = lowest variate, and Ma = mean of the distribution.

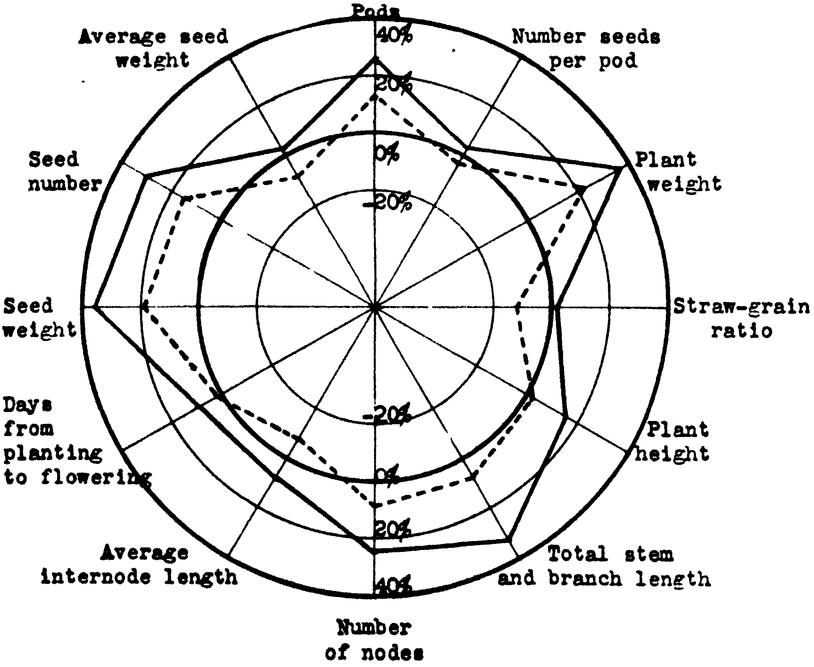

FIG. 1.—Diagram showing average percentage increase of hybrids over average of parents and over higher parents for the characters indicated.

As pointed out by Winter (9), the denominator gives a rough measure of the skewness of the distribution, while the second term of the numerator measures the range. Furthermore, this formula gives an abstract number that is not affected by the magnitude of the mean as is the coefficient of variability, and therefore may be used to compare the variability of distributions measured in different units.

Data on the F_1 generation are also included in the tables to give comparisons with the F_2. It is realized that such comparisons can only be indicative or suggestive, since the F_1's and F_2's were grown in different years, on different fields, and with different spacings. The actual and interpolated F_1 data are given. In interpolating the data the average of the parental types compared with the F_1 plants was, in one case, assumed to be comparable to the average of the mean parental types compared with the F_2 and, in the other case, comparable to the average of the maximum plants of the parental types grown in comparison with the F_2. The average of the parental types, with which the F_2's were compared, was divided by the average of the parental plants with which the F_1 was compared. This gave the factor by which the actual F_1 value was multiplied to secure the interpolated yield.

YIELD

The practical value of hybrid vigor in the soybean is determined largely by the possibility of securing vigorous segregates in the F_2 generation which will transmit this vigor to their offspring.

In the case of the soybean, as with other crop plants, yield is the principal characteristic in which we are interested. Yield is here used with special reference to seed production.

A comparison of the yields of the parental and F_2 populations of four crosses is given in Table 4. In the case of the Chimera x 345 F_2 populations, the mean of the F_2 was intermediate between the means of the parental strains. In the other three comparisons, there was no significant difference between the means of the parental lines or between the means of the F_2 populations and the means of the parental lines.

The F_2 range in yield extends in most cases approximately from the lowest variate of either parental line to the highest variate or above. In the Tall Manchu x A. K. 2 F_2 there was one segregate that yielded 67.38 grams, while the best plant of either parent was a Tall Manchu yielding only 58.27 grams. There is a possibility that this difference was due to the combination of different growth factors, but probably it could be accounted for on the basis of a difference in soil fertility. In the A. K. 114 x 394 F_2, however, there was a segregate that yielded 111.17 grams which was more than twice the yield of any plant in the parental strains or any other plant in the F_2 population. This difference was too great to be accounted for on the basis of soil fertility.

In three of the comparisons, the variability of the F_2 as measured by Weinberg's formula was higher than for either parental line, as

F_2 and parental populations	No. plants	W	Mean yield in grams	Range Minimum	Range Maximum	F_1 and parents	No. plants	Observed yield in grams	Interpolated yield based on parental average*	Interpolated yield based on parental maximum*
Chimera	133	1.74	11.95± .23	2.58	22.99	Chimera	2	19.14	8.00	18.81
F_2	406	2.41	16.42± .25	1.20	43.30	F_1	2	54.58	22.81	53.65
345	266	2.35	19.69± .33	2.34	51.35	345	2	56.48	23.61	55.52
A. K. 114	170	2.37	22.93± .42	3.42	53.17	A. K. 114	1	56.92	22.28	46.67
F_2	321	2.41	22.86± .35	4.16	111.17	F_1	1	72.42	28.35	59.38
394	125	2.47	19.98± .44	1.50	37.00	394	1	52.72	20.64	43.23
Early Manchu	59	3.18	33.23±1.08	8.40	70.76	Early Manchu	1	47.15	33.16	66.48
F_2	84	3.70	34.29±1.12	2.88	70.66	F_1	1	44.68	31.42	63.00
A. K. 3	40	3.15	31.27±1.26	2.15	58.80	A. K. 3	1	44.56	31.33	62.83
Tall Manchu	214	2.47	21.56± .41	2.00	58.27	Tall Manchu	1	44.85	20.05	55.17
F_2	337	2.63	21.81± .37	0.90	67.38	F_1	1	73.96	33.06	90.97
A. K. 2	240	2.14	20.12± .32	3.10	56.46	A. K. 2	1	48.38	21.63	59.51

*See text for explanation.

TABLE 5.—*Comparison of the F_1 and F_2 populations with their parents in number of seeds per plant.*

F_2 and parental populations	No. plants	W	Mean number of seeds per plant	Range Minimum	Range Maximum	F_1 and parents	No. plants	Observed no. seeds per plant	Interpolated no. seeds per plant based on parental average*	Interpolated no. seeds per plant based on parental maximum*
Chimera	133	4.41	77.44±1.51	12	150	Chimera	2	115.5	49.62	111.46
F_2	406	6.86	121.60±1.94	7	308	F_1	2	328	145.96	316.52
345	267	6.04	161.33±2.50	20	367	345	2	420.5	187.12	405.78
A. K. 114	170	5.91	160.0±2.80	20	370	A. K. 114	1	301	145.8	299.2
F_2	321	6.03	158.3±2.31	30	715	F_1	1	394	190.8	391.6
394	125	6.90	155.8±3.39	10	277	394	1	350	169.5	347.9
Early Manchu	59	8.65	214.4±6.89	46	375	Early Manchu	1	295	226.4	406.5
F_2	84	9.20	253.8±7.52	22	518	F_1	1	352	270.1	485.1
A. K. 3	40	3.97	235.3±4.31	16	431	A. K. 3	1	290	222.5	399.6
Tall Manchu	214	6.78	182.1±3.22	15	471	Tall Manchu	1	322	157.3	409.6
F_2	337	7.74	182.4±3.02	8	506	F_1	1	502	245.2	638.5
A. K. 2	240	6.26	167.6±2.61	29	440	A. K. 2	1	394	192.5	501.2

*See text for explanation.

one would expect. In the case of the 394 strain the variability slightly exceeds that of the F_2. This greater variability in the case of the parental strain is probably due to the relatively small number of plants which would give a higher standard deviation.

The F_1 data compared with the F_2, in Table 4, show that in two of the crosses the observed yield of the F_1 exceeded that of any segregate in the F_2. In the A. K. 114 x 394 and the Early Manchu x A. K. 3 crosses, there were F_2 plants that yielded higher than the F_1. When the average of the means of the parental strains compared with the F_2 was used to interpolate the F_1 yields, three of the four F_1's were above the F_2 average in yield. However, there were segregates in all but one of the F_2 populations that yielded at least twice as much as the interpolated F_1 yields. When the average of the maximum plants in the parental strains grown in comparison with the F_2 was used in interpolating the F_1 yields, the interpolated F_1 yields were much higher than the average F_2 yield and exceeded the highest segregates in the F_2's in two of the crosses.

NUMBER OF NORMAL SEEDS PER PLANT

If seed size remains fairly constant, the yield of seed per plant will obviously be dependent upon the number of seeds produced.

As in the case of yield, the mean of the Chimera x 345 F_2 was intermediate between the parental types for number of seed produced per plant (Table 5). In the other F_2's the means compare favorably with the means of the higher producing parental lines. It might appear as though the difference of 18.5 between the means of the Early Manchu x A. K. 3 F_2 and the A. K. 3 was significant, but the probable error of the difference here equals 8.67.

The increased range in the F_2's over the parental strains is more marked in the case of number of seeds than in yield. The data show an increase in range for the parental 345 strain over the F_2 in the case of the Chimera x 345 cross. In the case of the Early Manchu x A. K. 3 and Tall Manchu x A. K. 2 F_2's, a few plants produced more seeds than any plant in either parental population. Then, there was the segregate in the A. K. 114 x 394 F_2 that produced 715 seeds, while the highest plant of the parents produced only 370.

The variability relationships in number of seeds per plant were very similar to those found in the case of yield. The 345 strain was almost as variable as the F_2, while for the 394 strain $W = 6.90$ compared to $W = 6.03$ for the A. K. 114 x 394 F_2.

Using the average of the mean number of seeds produced by the parental types grown in comparison with the F_2, in interpolating the F_1 number of seeds, the F_1's were all well above the means of the F_2 population. There were segregates in all the F_2 populations that produced more seeds than did the F_1, using the interpolated yields. When the average of the maximum number of seeds produced by the parental plants, grown in comparison with the F_2, was used in interpolating the F_1 data, the F_1 values exceeded the maximum segregate of the F_2 in two crosses. In two cases the interpolated data gave a higher value than the actual number of seeds produced.

PLANT HEIGHT

Plant height has been considered by some investigators as the best criterion of hybrid vigor. The comparative data on plant height contained in Table 6 indicate that partially dominant factors were concerned. The mean heights of the F_2 populations are intermediate between the means of the parental types in all four crosses. However, where there was a marked difference in the mean height of the parents, as in the Chimera x 345 and the A. K. 114 x 394 crosses, the mean of the F_2 population was closer to that of the taller parent.

The range in height was greater in the F_2's in all cases, except the A. K. 114 x 394 F_2. Two plants of the 394 strain were below any in the F_2 in this cross.

The variability was greater in the F_2 than in the parental populations for all crosses, except the Early Manchu x A. K. 3 where the F_2 had a variability, as measured by Weinberg's formula, of 2.52, while the A. K. 3 has a variability of 3.15.

The actual heights of the F_1's given in Table 6 are below those of the tallest segregates in the F_2 in all cases, except in the Tall Manchu x A. K. 2 cross where the tallest F_2 plant is 104 cms, while the F_1 plant is 107 cms in height. When the average of the means of the parental strains was used in the interpolation, there were some segregates in each F_2 population that exceeded the interpolated height of the F_1 plants. When the average of the maximum parental plants was used in the interpolation, the heights of the F_1's were exceeded by segregates in the F_2 populations in the Chimera x 345 and the A. K. 114 x 394 F_2's.

DAYS FROM PLANTING TO FLOWERING

The date of flowering is closely associated with the relative date of maturity and is a record which is readily and accurately taken.

The mean of the number of days from planting to flowering is higher for the F_2 populations than for either parent except in the

TABLE 6.—*Comparison of the F_1 and F_2 populations with their parents in height.*

F_2 and parental populations	No. plants	W	Mean height, cms	Range Minimum	Range Maximum	F_1 and parents	No. plants	Observed height, cms.	Interpolated height based on parental average*	Interpolated height based on parental maximum*
Chimera	132	2.21	42.08± .31	28	52	Chimera	2	34.5	34.22	46.26
F_2	406	4.06	77.81± .70	25	134	F_1	2	97.5	96.72	130.75
345	261	2.01	84.42± .37	40	119	345	2	93.0	92.26	124.71
A. K. 114	170	2.00	83.3 ± .25	68	98	A. K. 114	1	84	92.2	113.8
F_2	321	2.68	67.7 ± .38	42	98	F_1	1	63	69.1	85.4
394	124	2.27	49.5 ± .44	22	66	394	1	37	40.6	50.1
Early Manchu	59	2.50	69.9 ± .56	48	79	Early Manchu	1	84	70.9	85.9
F_2	85	2.52	72.8 ± .79	30	105	F_1	1	90	75.9	92.1
A. K. 3	38	3.15	76.1 ±1.07	55	98	A. K. 3	1	89	75.1	91.0
Tall Manchu	213	1.90	73.7 ± .25	54	87	Tall Manchu	1	91	85.8	101.7
F_2	337	2.34	76.2 ± .36	32	104	F_1	1	107	100.9	119.6
A. K. 2	239	2.12	78.1 ± .29	52	93	A. K. 2	1	70	66.0	78.3

*See text for explanation.

TABLE 7.—*Comparison of the F_1 and F_2 populations with their parents in number of days from planting to flowering.*

F_2 and parental populations	No. plants	W	Mean in no. days	Range Minimum	Range Maximum	F_1 and parents	No. plants	Observed no. days	Interpolated no. days based on parental average*	Interpolated no. days based on parental maximum*
Chimera	126	0.84	56.23±.01	55	62	Chimera	2	55.5	61.16	65.49
F_2	394	2.02	61.34±.18	47	74	F_1	2	62.5	68.88	73.75
345	234	0.89	56.77±.04	55	59	345	2	47	51.79	55.46
A. K. 114	167	1.66	57.26±.12	48	62	A. K. 114	1	44	54.4	60.7
F_2	311	2.03	53.92±.16	45	65	F_1	1	46	56.9	63.5
394	123	2.00	50.26±.18	47	58	394	1	43	53.1	59.3
Early Manchu	57	1.98	56.91±.26	49	60	Early Manchu	1	47	57.0	61.0
F_2	84	1.92	59.45±.32	51	73	F_1	1	50	60.7	64.9
A. K. 3	38	1.49	57.16±.28	50	62	A. K. 3	1	47	57.0	61.0
Tall Manchu	212	1.96	55.75±.16	47	61	Tall Manchu	1	43	53.4	57.6
F_2	335	2.03	60.45±.22	48	89	F_1	1	47	58.4	63.0
A. K. 2	238	1.03	57.28±.07	48	61	A. K. 2	1	48	59.6	64.3

*See text for explanation.

A. K. 114 x 394 cross where the F_2 is intermediate, as shown by the data in Table 7. This indicates an accumulation, from both parents, of factors retarding or prolonging growth and development. However, the range is greater in the F_2's than in the parental strains.

The variability in number of days from planting to flowering is greater in the F_2's than in the parental populations, except in the Early Manchu x A. K. 3 cross where $W = 1.98$ for the Early Manchu and for the F_2 population, $W = 1.92$.

In number of days from planting to flowering, there were some nteresting relationships between the F_1 and F_2 populations (Table 7). In the Chimera x 345 cross, the observed number of days from planting to flowering for the F_1 compare very well with the mean of the F_2. In the other three crosses the F_1's compare very well with the earliest F_2 segregates. When the F_1 data were interpolated by using the average of the parental means, the F_1 number of days was increased above the observed. When the latest plants in the parental populations were used in the interpolation, the comparative lateness of the F_1's was increased still more. However, all the F_2 populations included segregates that were later than either interpolated F_1 value.

SUMMARY OF THE F_2 RESULTS

The mean seed yield and the number of normal seeds produced per plant of the F_2 were intermediate between the parental strains, where there was a marked difference between the parents; in other crosses the mean of the F_2 did not differ significantly from the parental means. However, there were segregates in some of the F_2's that exceeded all of the parental plants. The increased range in the F_2 over the parental strains was more marked in the case of number of seeds than in yield.

The F_2 results indicate the presence of partially dominant factors for height in the Chimera x 345 and the A. K. 114 x 394 crosses, where there was a marked difference in the mean heights of the parents.

With regard to the number of days from planting to flowering, the means of the F_2's were higher than the means of their respective parental strains, with one exception. This indicates either the accumulation, from both parents, of factors retarding or prolonging growth and development, or simply the result of hybridity.

As a rule, the F_2 populations were more variable than the parental strains as measured by Weinberg's formula. However, there were a few cases where one or the other parental strain gave a higher value for W than the F_2. The F_2 range also usually extended from the maximum to the minimum of either parental line or beyond.

DISCUSSION

Most investigators who have studied hybrid vigor have made comparisons between the hybrid and the average of the parents. This seems logical on the basis of incomplete dominance of such quantitative factors. But to be of value from the viewpoint of the practical plant breeder, the hybrid must be better than either parent, at least in some factors affecting vigor and yield. Consequently, it was thought that comparisons made with the better parent would be of greater significance than those made with the average of the parents.

In making this study it was realized that it would be desirable to have a number of F_1 plants from the same cross, but due to the difficulties of making crosses in soybeans this was found impractical.

The correlation ($r = 0.816 \pm .040$) between days from planting to flowering of the hybrids with the late parents indicates that lateness was dominant. The one exception, where one of the Elton x 394 hybrids was earlier than either parent, may be readily explained in that this was a cross between two early types both carrying recessive factors for maturity. On the other hand, the high correlations of the rest of the characters of the hybrids with the average of the parents indicate that most of these quantitative characters were intermediate in inheritance and probably dependent upon partially dominant factors.

The diagram in Fig. 1 indicates that the best criteria of hybrid vigor were seed weight, seed number, pod number, plant weight, plant height, total stem and branch length, and number of nodes. This diagram also indicates that in the hybrids the number of parts, such as seeds and nodes, was increased more than size of parts, such as average seed weight and average internode length. In this connection, it is interesting to note that the correlation coefficient between yield in the hybrids and number of nodes ($r = 0.797 \pm .051$) is about twice that between yield and the average internode length ($r = 0.357 \pm .123$).

The F_2 results are open to criticism since there were more plants of the F_2 studied than of either parental type. It was realized that the greater the number, the greater the range. On the other hand, it was considered that the variability as measured by Weinberg's formula was comparative, since the effect of the greater range in the F_2 would be offset by the smaller numbers in the parental populations.

The hybrids equalled or exceeded the taller parents in height where there was considerable difference in the height of the parents. When the heights of the hybrids were correlated with the average heights of the parents, r = 0.870 ± .030 and when correlated with the taller parent r = 0.702 ± .062 (Table 3). The hybrids were, therefore, intermediate in most cases between the parents in height. The F_2 of the Chimera x 345 cross gave a skew distribution indicating that the tallness of the 345 parent was dominant.

As previously shown, late flowering was dominant in the F_1 generation in these crosses. However, the F_2 populations show that this is not a simple 3:1 relationship. The modes of the F_2 distribution further indicate that dominant factors are concerned, while the extremely late plants indicate the presence of modifying factors that tend to delay flowering in certain crosses.

Although many of the early botanists observed the occurrence of increased vigor in hybrids when closely related plants were cross-fertilized, Darwin (1) was the first to attempt a logical explanation of this phenomenon. He attributed the increased vigor to a difference in the sexual elements of the crossed plants.

Theories for the explanation of hybrid vigor based upon some form of physiological stimulation, due primarily to the heterozygous condition of the zygote, are gradually being superseded by the theory of dominant growth factors which explains hybrid vigor on a Mendelian basis.

Jones (2) has illustrated the theory of dominant growth factors on the basis of additive factors that have a simple cumulative effect. In the light of our present knowledge of the inheritance of such quantitative factors, it would seem that most of them are only partially dominant. On this basis let us assume that the pure recessive condition forms an irreducable base for vigor, unless acted upon by some abnormal deleterious factor. Further, let us assume that each of these dominant factors has an effect of 2 when present in the heterozygous condition and an effect of 3 when homozygous. On such an assumption, letting the figures represent the relative vigor of the plants, we would secure results as illustrated below:

Female	Male	Hybrid
AA bb CC 6	AA BB cc 6	AA Bb Cc 7
AA bb cc 3	aa BB cc 3	Aa Bb cc 4
AA bb CC 6	AA BB CC 9	AA Bb CC 8
AA bb CC 6	aa BB cc 3	Aa Bb Cc 6

Of course there are probably many more than three factors concerned. On the assumption of more factors this explanation would easily account for the results secured from the soybean crosses previously described. According to this explanation, there is a possibility of securing segregates that are higher as well as those that are lower than the F_1. Our results with the soybean indicate that both types have been secured. It remains to be seen whether or not these types are homozygous or can be made so without reducing yield.

CONCLUSIONS

1. Of the plant characters studied, yield of seed, number of seeds, plant weight, and total stem and branch length seem to be the best criteria of hybrid vigor in soybeans.
2. As the yield of seed increased, the number of seeds and nodes increased more than the average seed weight or the length of internode.
3. There was a marked variation in comparative vigor among the different crosses.
4. Correlating the characters of the hybrids with the parental average gave a higher coefficient than correlating with the higher parent, except in the case of days to flowering where the coefficient was higher when correlating with the late-flowering parents.
5. Transgressive segregation occurred in the case of seed yield, seed number, height of plant, and days from planting to flowering.
6. On the basis of results obtained, hybrid vigor and transgressive segregation were explained by partial dominance of growth factors having a cumulative effect.

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REACTIONS OF ELECTRODIALYZED HUMUS AND BENTONITE AND APPLICATION OF THE METHOD[1]

ARTHUR O. ALBEN[2]

INTRODUCTION

In the electrodialysis of different soils it was noticed that the amounts of bases extracted varied considerably without any apparent reason. As an example of this variation in base exchange content, the results from the electrodialysis of four different soils are given in Table 1.

TABLE 1.—*Milliequivalents of bases extracted from different soils.*

Hours of electrodialysis	M. E. Clinton silt loam	M. E. Tama silt loam	M. E. Carrington loam (virgin)
3	9.72	12.45	—
6	—	—	7.65
9	1.59	3.00	—
18	—	—	7.85
21	0.85	0.45	—
24	—	—	5.13
30	—	—	1.74
33	0.31	0.29	
42	—	—	1.00
45	0.23	0.25	—
54	—	—	0.29
66	—	—	0.13
Totals	12.70	16.44	23.79

Twenty-three milliequivalents of bases were extracted from a virgin Carrington loam, 16 from a Tama silt loam, and 12 from a Clinton silt loam. All three soils had an acid reaction; the Tama silt loam had a pH of 5.4, the Carrington loam a pH of 5.7, and the Clinton silt loam a pH of 6.0.

Considering the texture of the soils and their reaction, it would be expected that the Clinton silt loam would contain the largest amount of replaceable bases, yet, it has the smallest amount, almost half of that of the virgin Carrington loam which is more acid and lighter textured. The Tama silt loam, also, gave a larger amount of extracted bases than the Clinton. The texture of these two soils was the same, but the Tama was more acid than the Clinton. The only apparent reason that would account for the difference in the base exchange content of these three soils when their texture and reaction were considered was the differing quantity of organic matter contained in them. The virgin Carrington loam was the coarser textured with the highest amount of exchangeable bases. Judging by appearance this soil seemed to be the highest in organic matter of the three, while the Clinton with the lowest amount of replaceable bases was also lowest in organic matter.

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[1] Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Part of a thesis submitted as partial fulfillment for the requirements for the degree of doctor of philosophy, Iowa State College. Received for publication November 4, 1929.

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It is generally accepted that base exchange reactions take place in the colloidal complex. The part played in these reactions by the organic and inorganic constituents of the soil complex has not been fully established. The following work was undertaken to throw some further light on this soil problem.

HISTORICAL

Gedroiz (2)[3] considers that humus takes part in base exchange reactions. He treated soil with 10% hydrogen peroxide and warmed it between 30° and 40°C to rid it of organic matter. Before treatment the replaceable calcium was 0.810 and after treatment 0.056%. Experiments were also carried out on clays freed of organic matter. While he does not consider the evidence conclusive, he believes that the organic matter and inorganic colloids take part in base exchange reactions.

Hissink (4, 5) in his work on the application of lime to soils found that the adsorptive capacity of humus to clay substance was in the ratio of 176:1,225. The figures were obtained by dividing the humus and clay substance by the total bases the materials were capable of holding. Thus, the humus substance has a far greater adsorptive capacity than the clay substance, about 7:1. Hissink considers the figures an approximation only, as the humus soils were not free of clay nor were the clay soils entirely free from humus.

Burgess and McGeorge (1) do not consider that humus has a true base replacement capacity. In their opinion, the so-called organic humates have no capacity for base replacement other than a variable physical adsorption. From their experiments they conclude that treating the soil with hyrdogen peroxide has an injurious effect on the base exchange reactions of the zeolite content.

Kerr (8) finds organic matter to possess a high base exchange capacity. The total exchange capacities of three soils were determined before and after treatment with hydrogen peroxide. He found the adsorption capacity of these soils due to organic matter to be from 7 to 28%.

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[3] Reference by number is to "Literature Cited," p. 325.

The review of literature shows no general agreement of ideas regarding the function of organic matter in base exchange reactions.

EXPERIMENTAL

In this work the reactions of humus were compared with that of bentonite. Bentonite was chosen because it is a naturally occurring soil colloid, free of organic matter, with a high base exchange capacity as compared with other soil colloids.

The humus was extracted from a peat soil made up of 50% organic matter. The peat was washed with 1% HCl till the percolate was free of calcium and then washed with water till free of chlorides. The washed humus was transferred to a beaker and 4% ammonia added. After standing for 15 hours, the supernatant liquid was poured off and passed through a Pasteur-Chamberland filter. The material thus secured varied in ash content somewhat, but some of it had an ash content as low as 1% after being electrodialyzed for several weeks.

The colloidal bentonite used was of the material remaining in suspension after four months standing of a dispersion of 60 grams of bentonite in 16 liters of distilled water.

ADSORPTIVE CAPACITY OF HUMUS AND BENTONITE

A T-S according to Hissink (3) was run on bentonite and humus. The bentonite had been electrodialyzed to a pH of 2 and the humus to a pH of 2.37. After electrodialysis, the material was dispersed and 10 cc of the resulting suspension placed in Erlenmeyer flasks. Varying amounts of $Ba(OH)_2$, 0.0522 N for the bentonite and 0.1317 N for the humus, were added. The bentonite suspensions were made up to 50 cc and humus to 70 cc by additions of water. Three runs were made on the humus before enough $Ba(OH)_2$ of the proper strength was found to get a straight line from the plotted results. The results figured on the basis of 10 grams dry weight of bentonite and humus are shown in Figs. 1 and 2.

The humus took up 162 milliequivalents of $Ba(OH)_2$ as against 22 for the bentonite, a ratio of approximately 7:1.

REACTIONS OF ELECTRODIALYZED HUMUS

Humus was extracted in the usual manner, dried on the steam bath, electrodialyzed, and dried again. The ash content was determined on a portion of it and found to be 5%. The dried humus was washed with a solution saturated with calcium chloride till the percolate coming through had the same reaction as the calcium

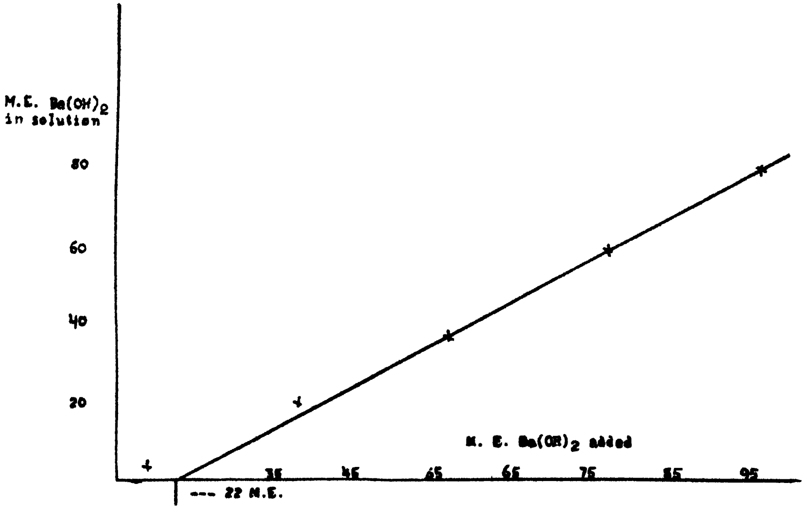

FIG. 1.—T–S for 10 grams of bentonite.

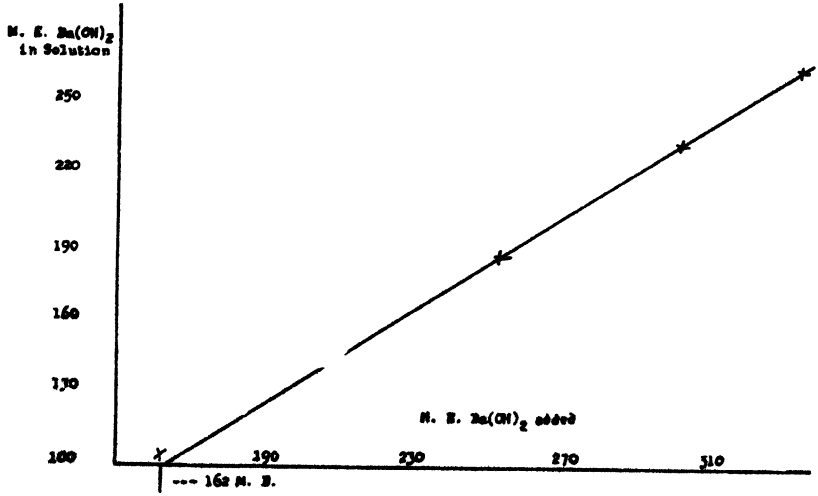

FIG. 2.—T–S for 10 grams of humus.

chloride solution with which the material was being washed. The material was washed free of chlorides and the reaction determined. Before treatment with calcium chloride the reaction was 3.15, after treatment 4.78.

Another portion of humus was treated as before, except that it was not dried down at any time. Before being treated with calcium chloride it had a pH of 2.67, after treatment 8.2.

Electrodialyzed humus seems to be less active chemically after it has been dried down. It dries down into a coal-like substance that has no visible solubility in water even after standing for several weeks. Some dried electrodialyzed humus was treated with a potassium chloride solution. There was no apparent reaction with the cold solution and little apparent reaction after boiling for an hour. Yet, electrodialyzed humus, undried, treated with a potassium chloride solution became so dispersed no available filter would hold it. The dried electrodialyzed humus reacted readily enough with potassium hydroxide.

There is some evidence in the literature that humus is considered as being rather inert chemically. The word "humus" probably does not have the same meaning to all soil workers. The material itself can easily vary considerably because of the different conditions under which it is formed. Lack of agreement on what constitutes humus and the probable variability of the material itself could account for the variable results reported.

The humus material worked with in these experiments did not appear to be inert, some evidence of which has already been presented. In the electrodialyzing cell, the material had a negative charge as it collected on the positive membrane. Photographs were made of membranes used in the electrodialysis of humus. They are shown in Fig. 3.

The picture at the left is that of the membrane on the positive side, showing the humus adhering to the membrane. The picture on the right shows the negative membrane free of humus.

Some electrodialyzed humus, pH 3.7, was titrated with 0.1062 N sodium hydroxide. The curve plotted from the results is shown in Fig. 4. The shape of the curve indicates that the humus material probably contained a mixture of acids, although a trivalent acid could give the same type of curve.

Titrations of electrodialyzed humus were made with a conductivity apparatus, using calcium hydroxide, aluminum hydroxide, and ferrous oxide. The humus had a pH of 3.6 at the start of the titration. The dry weight of the humus used was 0.328 gram. The amounts of bases used and the results obtained are shown in Figs. 5, 6, and 7.

The first reading was that of the humus itself. As the H ion is the fastest ion, the first reading is due mainly to that ion. When a base is added and reaction takes place, some of the H ions are neutralized, causing the conductivity to drop. The result is a downward trend in the plotted curve. The next fastest ion to the H ion is the OH ion. The curve takes an upward trend when base is added after neutralization has taken place. The shapes of the curves indicate that calcium hydroxide, ferrous oxide, and aluminum hydroxide reacted with the

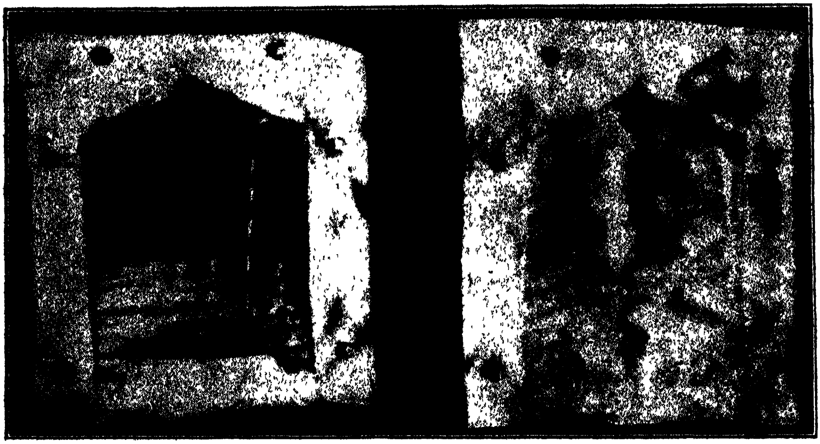

FIG. 3.—Left, membrane on positive side; right, membrane on negative side.

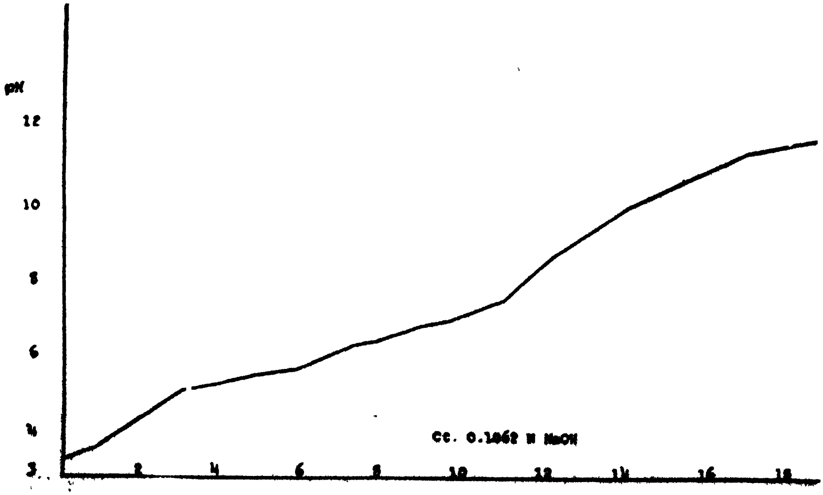

FIG. 4.—Titration of humus with NaOH.

humus. The titration with aluminum hydroxide was not completed as interest was primarily in whether or not aluminum would combine with humus.

An attempt was made to form an aluminum humate, using electrodialyzed humus and aluminum chloride. The experiment was un-

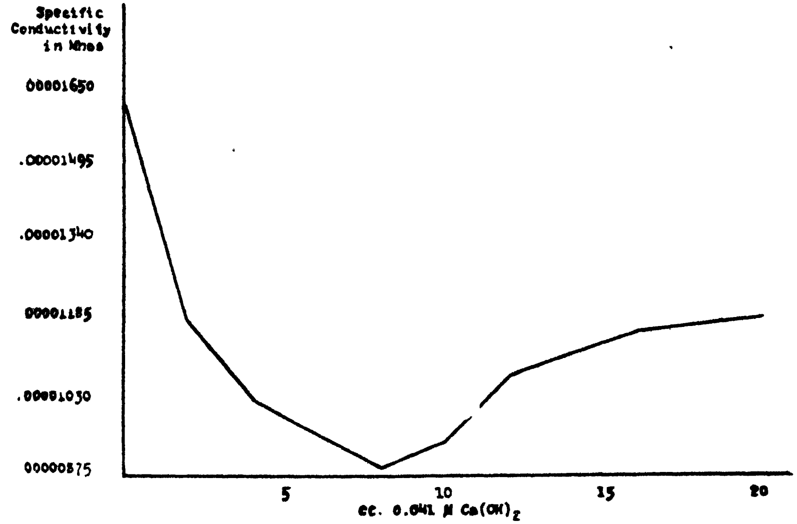

FIG. 5.—Conductivity titration of humus and Ca(OH)$_2$.

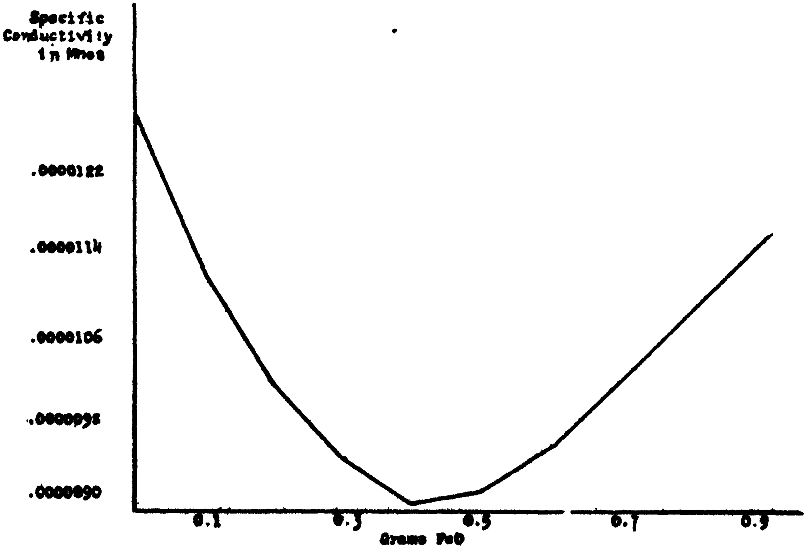

FIG. 6.—Conductivity titration of humus and FeO.

successful. The reason was evident after the reaction of the aluminum chloride had been taken. Some reactions of aluminum chloride are given in Table 2.

TABLE 2.—*Some reactions of aluminum chloride.*

Normality	pH
0.001	4.31
0.010	3.75
0.100	3.65
1.000	3.10

The results in Table 2 show why aluminum humate was not formed with the use of aluminum chloride. The H ion is more abundant in solutions of this salt than in the suspensions of electrodialyzed humus.

REACTIONS OF ELECTRODIALYZED BENTONITE

A portion of the colloidal bentonite previously mentioned was electrodialyzed for several days, removed from the cell, and dispersed in a small quantity of water. The resulting suspension had a pH of 2.0. Ten cc of this suspension were diluted to 100 cc, 10 cc of this new suspension diluted to 100 cc, etc. The dilutions and resulting pH are given in Table 3.

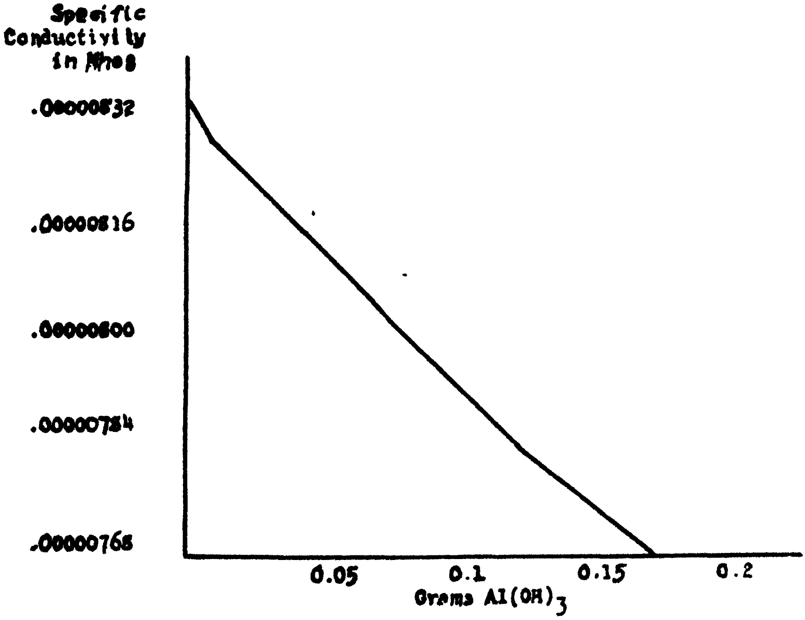

FIG. 7.—Conductivity titration of humus and Al(OH)$_3$.

The reaction drops off rather sharply after the second dilution. However, considering the fact that this material is a colloidal suspension and not a substance in solution, the acidic properties are rather marked.

TABLE 3.—*Reactions of electrodialyzed bentonite.*

Dilution	pH
Original material	2.00
1st dilution	3.40
2nd dilution	5.82
3rd dilution	6.53
4th dilution	6.84
Distilled water	6.84

Electrodialyzed bentonite was titrated in a conductivity apparatus with sodium hydroxide, ammonium hydroxide, calcium hydroxide, aluminum hydroxide, and ferrous oxide. The aliquots of bentonite contained 0.285 gram dry weight of bentonite which had a pH of 3.34 at the start of the titration. The results are shown in Figs. 8, 9, 10, 11, and 12. The curves in the figures indicate that bentonite reacted with ammonium, sodium, and calcium hydroxide and ferrous oxide, but did not react with aluminum hydroxide.

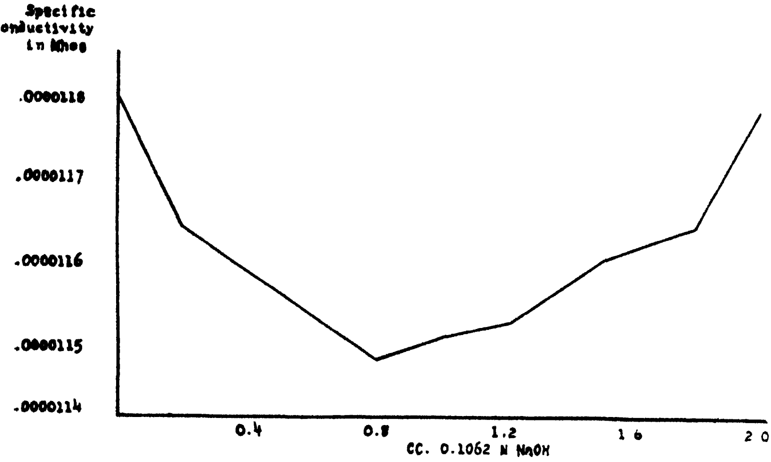

FIG. 8.—Conductivity titration of bentonite and NaOH.

DISCUSSION

One portion of humus was electrodialyzed to a pH of 1.5, giving a reaction equal to a 0.0316 N acid. The lowest reaction secured with bentonite was a pH of 2 equal to a 0.01 N acid. The humus gave an acid reaction three times as strong as the colloidal bentonite.

The humus worked with in the T-S experiment had seven times the adsorptive capacity of colloidal bentonite. The portion of humus on which this experiment was made had an ash content of 1% after it was electrodialyzed. If the organic matter in this sample was inert and the reaction due solely to a possible adhering zeolite, this zeolite would have had a base exchange capacity 700 times that of the colloidal bentonite. It is doubtful if such a zeolite exists. Mattson (9) found bentonite to be a material with a high ratio of SiO_2 to

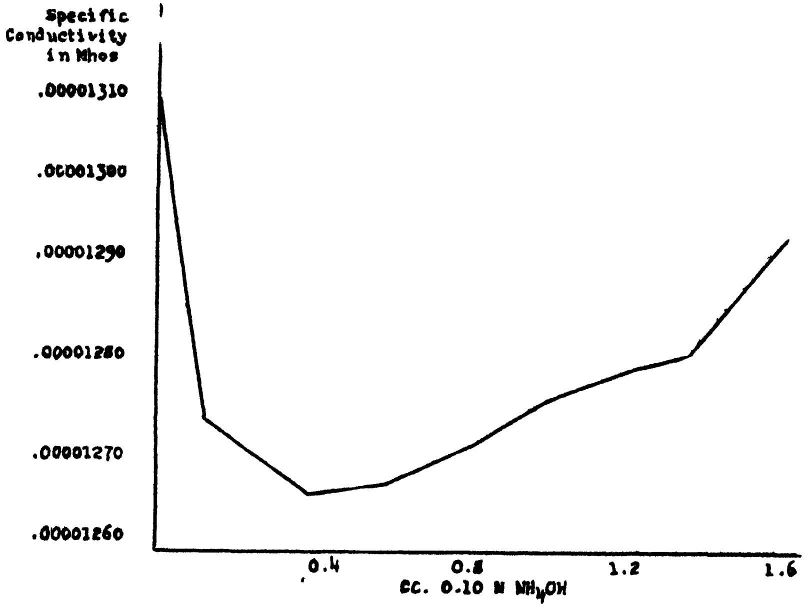

Fig. 9.—Conductivity titration of bentonite and NH_4OH.

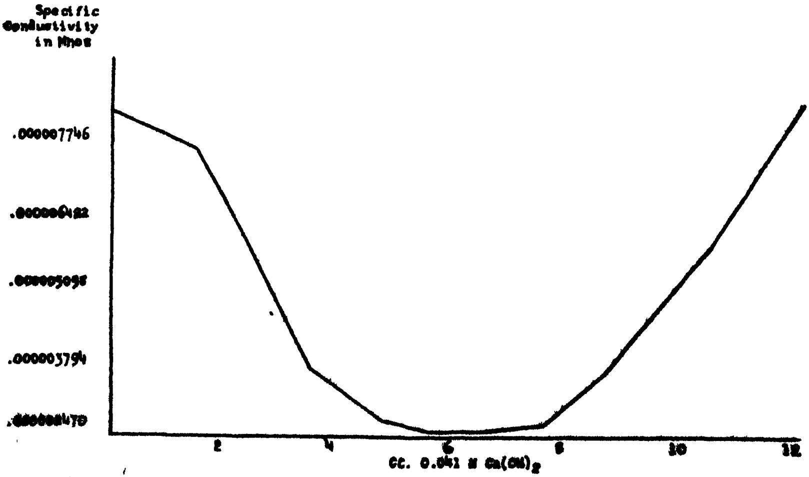

Fig. 10.—Conductivity titration of bentonite and $Ca(OH)_2$.

sesquioxides and to have a base exchange capacity equal to that of any material with which he worked.

It is evident that before a base exchange reaction can take place, a base must be present in the exchange complex. Sodium, potassium, calcium, and magnesium have long been considered to take part in base exchange reactions. The results in this work indicate that iron and aluminum could possibly take part in base exchange reactions as iron and aluminum humates were formed and also an iron "clayate."

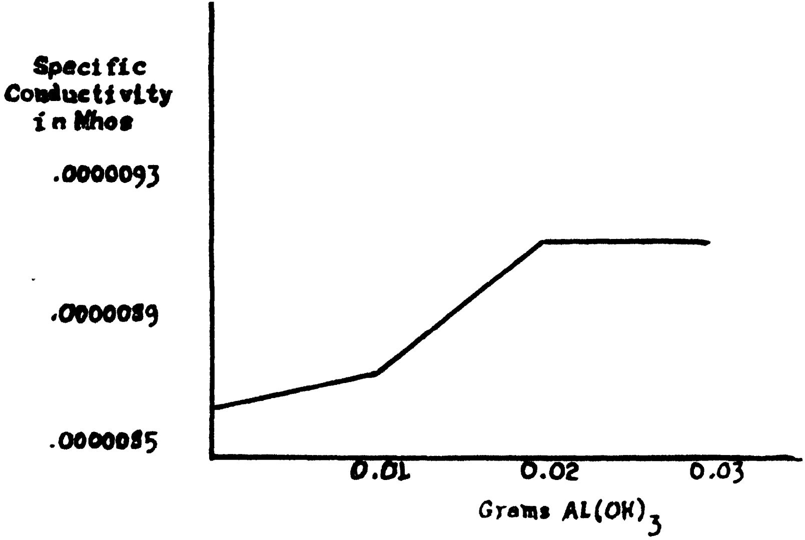

FIG. 11.—Conductivity titration of bentonite and $Al(OH)_3$.

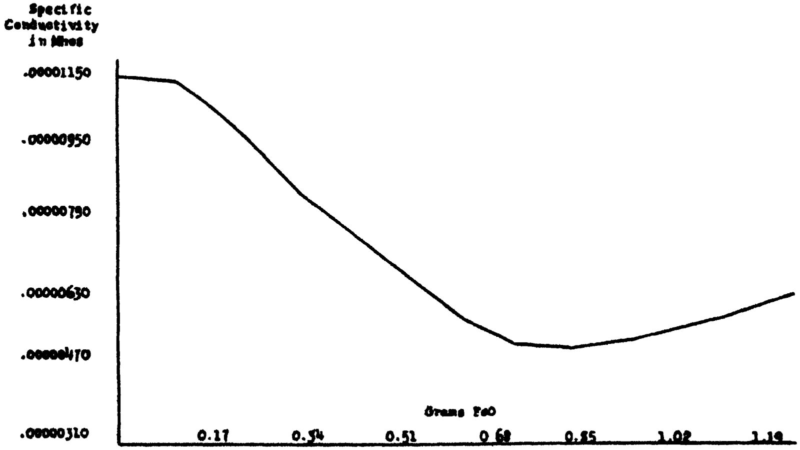

FIG. 12.—Conductivity titration of bentonite and FeO.

SUMMARY

1. Humus was found to have an adsorptive capacity seven times that of bentonite.
2. Humus was found to react with aluminum and calcium hydroxide and ferrous oxide.
3. Bentonite was found to react with ammonium, calcium, and sodium hydroxide, and ferrous oxide.
4. Bentonite did not react with aluminum hydroxide.

APPLICATION OF ELECTRODIALYSIS

ANALYSIS OF DIALYSATES FROM TWO ACID SOILS

A Tama silt loam and a Clinton silt loam, two acid soils, were electrodialyzed and changes made of the dialysates at 3-, 6-, 12-, 12-, and 12-hour intervals. Analyses were made of the bases and phosphorus present in the dialysates. The results are shown in Tables 4, 5, 6, and 7.

In computing milliequivalents, iron and manganese were both given a valence of two as they were thought to be more apt to occur at this valence than a higher one, especially as they were in the presence of organic matter.

Calcium was the most abundant element in the dialysates of both soils. The largest amount, 72 and 80%, of this element came out in the first three hours of electrodialysis. The amounts in subsequent changes decreased rapidly. The amount of magnesium was one-seventh of that of calcium. The largest amount, 45%, was in the first change. Magnesium, also, decreased in subsequent changes. The amounts of iron, aluminum, and manganese followed a general trend of the smallest amount in the first change, increasing amounts in the second and third changes, and decreasing amounts in the fourth and fifth changes. Total potassium averaged only 2.5% of the total calcium and only 2.4% of the total bases extracted. The amounts of phosphorus extracted from the two soils did not vary strikingly either in quantity or rate of extraction.

TABLE 4.—*Milliequivalents of bases and parts per million of phosphorus in Tama silt loam.*

Hours between changes	M. E. Ca	M. E. Mg	M. E. Mn	M. E. Al	M. E. K	M. E. Fe	P.P.M. of P
3	6.70	1.17	0.02	0.07	0.06	0.05	3.7
6	1.50	0.75	0.12	0.23	0.07	0.10	3.1
12	0.50	0.43	0.50	0.14	0.09	0.04	3.0
12	0.29	0.15	0.16	0.06	0.11	0.03	2.8
12	0.20	0.10	0.09	0.07	0.09	0.03	2.6
Total 45	9.19	2.60	0.89	0.57	0.42	0.25	15.2

TABLE 5.—*Milliequivalents of bases and parts per million of phosphorus in Clinton silt loam.*

Hours between changes	M. E. Ca	M. E. Mg	M. E. Al	M. E. Mn	M. E. Fe	M. E. K	P.P.M. of P
3	7.61	1.23	0.03	0.03	0.06	0.01	5.80
6	0.88	0.96	0.07	0.77	0.09	0.01	5.73
12	0.67	0.41	1.00	0.80	0.32	0.02	5.80
12	0.20	0.15	0.95	0.15	0.36	0.02	2.50
12	0.15	0.06	0.93	0.04	0.22	0.01	1.75
Total 45	9.51	2.81	2.98	1.79	1.05	0.07	21.58

TABLE 6.—*Percentage of each element in each change of the total amount for that element extracted from Tama silt loam.*

Change	Hours between changes	Ca %	Mg %	Mn %	Al %	K %	Fe %	P %
1.	3	72.89	45.00	2.24	12.28	14.29	19.96	24.34
2	6	16.34	25.00	13.49	40.35	16.66	40.00	20.39
3	12	5.44	17.30	56.18	24.66	21.42	16.01	19.73
4	12	3.15	5.76	17.98	10.52	25.19	12.00	18.42
5	12	2.17	3.84	10.16	12.28	21.42	12.00	17.10

TABLE 7.—*Percentage of each element in each change of the total amount for that element extracted from Clinton silt loam.*

Change	Hours between changes	Ca %	Mg %	Al %	Mn %	Fe %	K %	P %
1	3	80.21	43.79	1.00	1.67	5.71	14.28	26.73
2	6	9.23	34.12	2.39	43.03	8.57	14.28	26.55
3	12	7.04	14.59	33.56	44.69	30.40	28.59	26.87
4	12	2.10	5.33	31.84	8.37	34.29	28.59	11.58
5	12	1.57	2.13	31.28	2.23	20.95	14.28	8.10

REACTION OF ELECTRODIALYZED SOILS

The modified Mattson cell as described previously (6) was used in this experiment. The current was 250 volts. The cooling system kept the temperature of the cell from going above 25°C. The amperage varied with the course of the dialysis but did not rise over 2 amperes with two cells in use. The results for various changes on a Tama silt loam are shown in Table 8.

TABLE 8.—*Reaction of the various changes in the electrodialysis of a Tama silt loam.*

Change	Hours between changes	pH
1	3	2.12
2	6	2.10
3	12	2.06
4	12	2.06
5	12	2.04

The soil used had a pH of 5.7 at the start of the experiment. Three hours of electrodialysis brought the reaction down to a pH of 2.12. Forty-two hours more of dialysis decreased the pH only slightly, or to 2.04.

Kelley and Brown (7) report a pH of 4.5 for a soil electrodialyzed five days, Rost (10) reports securing a pH of 2.94, Wilson (11) a pH of 2.7, and Humfeld and Alben (6) a pH of 2.7. The soil reaction secured by means of electrodialysis depends on many factors, among which are voltage used, pH of original soil and amount of bases contained therein, amount of soil used, frequency of changes, length of run, and type of cell used. These factors account for the varying end-points reported.

COMEBACK OF PH OF ELECTRODIALYZED SOIL

Two portions of Tama silt loam and Clinton silt loam were electrodialyzed. One set of the electrodialyzed soils was kept under water through the course of the experiment and the other moistened, allowed to dry out, moistened again, etc. The results are shown in Table 9.

TABLE 9.—*Comeback of soil pH.*

Time	Set kept in water		Set allowed to dry out	
	Clinton silt loam	Tama silt loam	Clinton silt loam	Tama silt loam
Start	2.49	2.60	2.66	2.31
After 30 days	3.60	3.72	3.57	3.57
After 60 days	4.09	3.99	3.89	3.67
After 90 days	4.08	3.97	3.97	3.67

The set that was kept under water apparently reached equilibrium in 60 days at a pH of 4.0. The Clinton soil that was allowed to dry out reached practically the same end-point. The Tama soil that was allowed to dry out ended with a lower pH than the others. This soil contained more humus than the Clinton. The drying out of the humus, making it less reactive, might account for the lower pH reached by this soil.

ELECTRODIALYSIS OF A BASIC SOIL

A Webster silt loam with a pH of 7.7 was electrodialyzed. The results compared with those secured on an acid soil are shown in Table 10.

The last change of the Webster soil, ending at 225 hours, had as large an amount of bases as the last change of the Clinton soil, ending at 45 hours.

The displacement solution methods now in use on basic soils are not entirely satisfactory, as it is difficult to determine what portion of the bases extracted is due to the solubility of carbonates. Electrodialysis does not appear to be a promising method for these soils as carbonates decompose under the influence of the electric current. Also, it takes too long a time to reach the end-point for the method to be of practical value.

TABLE 10.—*Results with a basic soil compared with results with an acid soil.*

Hours of electrodialysis	M. E. Clinton silt loam (acid)	M. E. Webster silt loam (basic)
3	9.72	9.52
9	1.59	17.87
21	0.85	14.97
33	0.31	6.17
45	0.23	6.42
57	—	3.85
69	Total 12.70	2.79
81		2.10
93		1.63
105		1.57
129		1.63
141		1.10
153		0.95
165		1.21
177		0.78
206		0.99
213		0.30
225		0.27
		Total 74.12

SUMMARY

1. Results of the analysis of the dialysates from a Tama silt loam and a Clinton silt loam are given.
2. The reactions of a Tama silt loam during electrodialysis are listed. The final reaction was a pH of 2.04.
3. The reaction of an electrodialyzed soil came back to a pH of 4.0 in 60 days
4. Application of electrodialysis to basic soils is discussed.

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BIOMETRICAL RELATIONSHIPS OF CERTAIN CHARACTERS IN UPLAND COTTON[1]

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At the onset of any breeding program in plants it is necessary to know the ultimate possibilities of available material in order to avoid the wasting of much time and money. To accomplish this, it is necessary to consider the things that we desire to build into a variety for commercial use; then, to find out if the material to be worked with contains these ultimate possibilities. If the available material does not contain the characters desired in such a way as to obtain certain combinations by intra-strain or intra-varietal crosses and selections, it will then be necessary to introduce these certain characters or combinations of characters by crossing with unrelated varieties or species.

The work reported herein is the result of preliminary investigations on the possibilities of the Acala variety of cotton as to future breeding work. In this study not only were four strains or different varieties of Acala used, but two varieties of cotton were included which were unrelated to Acala At the outset it was desired to find out the situation with respect to the characters that go to make up yield and quality as regards their compared means of the different varieties in a minor way but mainly to ascertain the relationships of characters with each other as regards the possibility of their being correlated in certain degrees In this connection it might be well to call attention to some interesting relationships in small grains obtained by Hayes, Aamodt, and Stevenson (1)[3] and by Immer and Stevenson (2).

MATERIALS AND METHODS

The data included in this report were collected at State College, New Mexico, in the fall of 1928. State College is located in southern New Mexico, 40 miles north of El Paso, Texas, in the upper Rio Grande Valley. This valley is irrigated with water from the Elephant Butte Reservoir. The rainfall is slight, but the reservoir supplies water in sufficiency. The altitude is 3,838 feet.

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[1] Contribution from the Department of Agronomy, New Mexico Agricultural Experiment Station, State College, N. M. Credit is due Oris V. Wells of the Bureau of Agricultural Economics of the U. S. Dept. of Agriculture and Professor J. W. Branson of this college for their criticisms and assistance in connection with some of the calculations included in this paper. Received for publication October 1, 1929.

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[3] Reference by number is to "Literature Cited," p. 340.

Notes were taken on 100 random plants in each of six varieties. Data are presented on these six varieties, including an extra sample of 100 plants of the so-called College Acala.

College Acala is so named by farmers in New Mexico as to mean the seed obtained from the college. Originally, this seed was bred by the U. S. Dept. of Agriculture in California. From California such seed goes to the U. S. field station at State College, where the seed is increased and furnished to the New Mexico A. & M. College. The college further increases this seed and sells the increased seed in turn to certain farmers' seed associations. The farmers in turn grow this seed for further increase and distribute it generally to other farmers at a set minimum price. The organization built up to distribute pure seed from the college to the farmers is well perfected and is filling a great need of the farmers in this section.

Of the six varieties mentioned above, three are of western origin, namely, College Acala, Young's Acala, and Okra Leaf Acala; two of central and east Texas origin, Russell's Big Boll and Rogers' Acala; and one from the eastern part of the United States, Lightning Express. It should be borne in mind that there are two samples of College Acala, and where there is mention of seven varieties these two samples are included as separate varieties.

Notes were taken in the field on 100 plants per variety as to height, number of fruiting branches, number of vegetative branches, number of 4-lock bolls, and number of 5-lock bolls. Then, at this note taking time, a five-boll sample was taken on all plants having that many open bolls. On some plants less than five bolls were opened and where this occurred the open bolls found were picked and the number noted. No samples were taken from plants with no open bolls, hence eliminating them from all the reported correlation studies.

The samples collected were ginned on a small eight-saw gin adapted to ginning small samples and additional notes obtained on the following characters: Percentage of lint, length of lint, weight of lint per boll, and a calculated yield of lint per plant. This calculated yield was obtained by multiplying the total number of bolls by the weight per boll. Also, the total number of bolls was obtained by the addition of 4-lock bolls and 5-lock bolls. In certain places total number of branches will be mentioned. This means the number of fruiting branches plus number of vegetative branches. There is still another character, close-jointedness, that was used in some instances. This means the length of the internodes on the main stem and was obtained by dividing the height by the total number of branches.

In calculating for type, variability, and simple, partial, and multiple correlations, the usually accepted formulae were used. In calculating the partial and multiple correlations the procedure and methods of Wallace and Snedecore (5) were of inestimable value.

CHARACTERS STUDIED

For those who are not familiar with the cotton plant it is desired to explain some of the above-mentioned characters. The differences in fruiting and vegetative branches come from the mode of putting on fruit (squares or bolls). A square is a fruiting bud with its three bracts before flowering. After flowering it becomes a young boll. In fruiting branches the squares or bolls are borne direct on the branch, while on vegetative branches the fruit is borne on a secondary branch from the vegetative branch. Usually, the vegetative branches are the first branches to put out and the fruiting branches are borne just above these.

The difference between 5-lock and 4-lock bolls is readily understood, as it refers to the number of loculi contained in the boll. Upland cotton usually contains both 4-lock and 5-lock bolls. Some varieties contain a larger percentage of one or the other. It might be well to mention here that Egyptian cotton usually bears 2- and 3-lock bolls, while Sea Island cotton generally bears 3- and 4-lock bolls.

Percentage of lint refers to percentage of lint contained in the seed cotton, i.e , cotton before being ginned, or in other words, the lint plus seed before ginning.

TYPE AND VARIABILITY

The constants for type and variability for all mentioned characters for all varieties will not be shown here. However, it is desired to discuss briefly the variation in type and variability of the varieties.

The means for yield of lint in grams per plant ran from 29.57 ± 1.43 in Okra Leaf Acala to 64.07 ± 1.86 in College No. 1. In Okra Leaf the range ran from 5.5 to 95.5 grams per plant, while in College No. 1 the range was 15.5 to 155.5.

The means for weight of lint per boll ran from 1.77 ± .02 grams in Lightning Express to 3.17 ± .03 grams in Russell's Big Boll. The range of Lightning Express for weight per boll was 0.6 to 2.5 grams and for Russell's Big Boll 1.25 to 4.25 grams.

The highest mean as to length of lint was Rogers' Acala with 17.88 ± .05 sixteenths of an inch, having a range of only 16 to 19. The lowest mean length was College Acala No. 2 with 15.19 ± .06 sixteenths of an inch and with a range of 14 to 17.

The highest mean as to percentage of lint was College Acala No. 1 with 37.13± .13% with a range of 31 to 43%, and the lowest was Lightning Express with 32.92± .14% having a range of 28 to 40%.

There was only a difference of about 0.6 foot between the highest and lowest means as to height of plant, the tallest being College Acala No. 2 with a mean height of 3.782± .033 feet and a range of 2.25 to 5.03 feet. The shortest variety was Russell's Big Boll with a mean height of 3.138± .026 feet and a range of 1.85 to 4.05 feet.

The type as to number of fruiting branches can be represented by Lightning Express which had the highest mean number with 18.90± .16 branches, with a range of 9 to 23 branches, and Okra Leaf Acala with a mean of 13.56± .17 branches, with a range of 7 to 20.

The means of the varieties for total number of branches ran from 17.56± .30 branches, with a range of 8 to 31 branches, to 22.18± .29 branches, with a range of 11 to 35.

For number of vegetative branches per plant Okra Leaf Acala had the highest mean number, 4.04± .18 branches, with a range of 0 to 13. The lowest number of vegetative branches was Russell's Big Boll, 1.91± .09 with a range of 0 to 6.

The number of 4-lock bolls per plant was highest in Lightning Express with 19.65± .63, having a range of 5 to 60, and lowest in Russell's Big Boll with 2.85± .15 bolls having a range of 0 to 12.

In total number of bolls per plant Lightning Express was the highest with 31.50± 1.01 bolls, with a range of 10 to 75. The lowest mean number of bolls was found in Okra Leaf Acala with 11.50± .47 bolls having a range of 4 to 34. The means of the other varieties ran from 15 to 22 bolls per plant.

The means of the number of 5-lock bolls per plant ran from College No. 1 with 16.02± .44 bolls, having a range of 1 to 33, down to Okra Leaf Acala with 5.60± .27 bolls, with a range of 0 to 19, the other means falling between 11 and 15.

The type of close-jointedness, or the average length of internode on the main stem, is shown by the means which ran from 0.1606± .0019 tenth of a foot, with a range of 0.10 to 0.27, to 0.1920± .0031 tenth of a foot with a range of 0.12 to 0.43.

MULTIPLE CORRELATIONS

In cotton breeding there has been much difference of opinion on the importance of certain characters. Practical breeders are prone to emphasize one or more characters and overlook others that may or may not be important.

The two main things a cotton breeder should pay attention to are, yield of lint per acre and high spinning quality (6). Yield of lint is the result of the expression of many other characters. High spinning quality also involves several characters and each may be influenced by behavior of still other characters. Multiple correlations are an attempt to express the combined relationship of certain characters upon one other character.

In running the multiple correlations reported here only 8 of the 12 characters could be used. Three of the discarded characters were characters made up by the addition of two others or the division of the one by the other, and therefore the equations where they were used would not solve. The other character was discarded because it showed no significant simple correlations with the other characters.

In Table 1 are shown the multiple correlation coefficients (R's) of each of the certain characters with the other seven.

TABLE 1.—*Multiple correlation coefficients showing the combined association of seven characters with the eighth character and using each of the eight characters as the primary in each of the seven varieties.*

Varieties	Yield of lint per plant	Weight of boll	No. 5-lock bolls	No. 4-lock bolls	No. of vegetative branches	No of fruiting branches	Height of plant	Percentage of lint
College Acala No. 1	0.99	0.89	0.98	0.89	0.74	0.57	0.57	0.44
College Acala No. 2	0.98	0.83	0.97	0.88	0.70	0.91	0.86	0.68
Young's Acala	0.96	0.84	0.96	0.82	0.71	0.89	0.92	0.57
Rogers' Acala	0.98	0.85	0.99	0.91	0.57	0.81	0.90	0.72
Okra Leaf Acala	0.99	0.90	0.98	0.97	0.99	0.83	0.91	0.62
Russell's Big Boll	0.99	0.94	0.94	0.92	0.63	0.77	0.62	0.51
Lightning Express	0.99	0.84	0.96	0.97	0.65	0.46	0.66	0.48

It is to be noted that $R_{X.LHFECBA}$ was uniformly high for all varieties, the coefficients running from 0.96 in Young's Acala to 0.98 and 0.99 in the other varieties.[4] This shows that practically all the variation in yield can be explained on the basis of the characters used. Therefore, practically all the characters that make up yield have been noted. While this is true, characters like weight of bolls, number of 5-lock bolls and 4-lock bolls, etc., are of course influenced by fertility, moisture (6), etc., and were not taken into account.

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[4] Letters in correlation coefficients indicate as follows: A, percentage lint; B, height of plant in 10th's of a foot; C, number of fruiting branches; E, number of vegetative branches; F, number of 4-lock bolls; H, number of 5-lock bolls; L, weight of lint per boll; and X, yield of lint per plant.

TABLE 2.—*Partial correlation coefficients in seven cotton varieties of eight characters, one with each of the others, where the other six are held constant.*

Correlations	College Acala No. 1	College Acala No. 2	Young's Acala	Rogers' Acala	Okra Leaf	Russell's Big Boll	Lightning Express
			Yield				
XL	0.89±.01	0.65±.04	0.74±.03	0.68± 04	0.80±.03	0.91 ±.01	0.72±.03
XH	0.97±.004	0.95±.01	0.89±.01	0.98±.003	0.90±.01	0.96 ±.01	0.91±.01
XF	0.93±.01	0.83±.02	0.81±.02	0.87±.02	0.96±.01	0.90 ±.01	0.95±.01
XE	0.31±.06	—0.39±.06	0.03±.07	0.16±.07	—0.15±.07	—0.13 ±.07	—0.36±.06
XC	0.17±.07	0.49±.06	0.54±.05	0.46±.05	—0.37±.06	—0.09 ±.07	—0.02±.07
XB	—0.25±.06	0.00*	—0.51±.05	—0.77±.03	—0.57±.05	0.003±.07	—0.21±.07
XA	—0.34±.06	0.34±.06	—0.01±.07	0.48±.05	—0.18±.07	0.14 ±.07	—0.17±.07
			Weight of Boll				
LH	—0.86±.02	—0.56±.05	—0.56±.05	—0.69±.04	—0.64±.04	—0.88 ±.02	—0.56±.05
LF	—0.85±.03	—0.53±.05	—0.66±.04	—0.71±.03	—0.78±.03	—0.88 ±.02	—0.68±.04
LE	0.37±.02	0.40±.06	—0.19±.07	0.01±.07	0.02±.07	0.24 ±.07	0.23±.06
LC	0.21±.07	—0.37±.06	—0.22±.07	—0.25±.07	—0.24±.07	0.20 ±.07	0.14±.07
LB	0.46±.05	0.00	0.19±.07	0.33±.06	0.47±.06	—0.002±.07	0.15±.07
LA	0.55±.05	0.20±.07	0.32±.06	0.06±.07	0.49±.06	—0.25 ±.07	0.42±.06
			5-lock Bolls				
HF	—0.92±.01	—0.81±.03	—0.74±.03	—0.87±.02	—0.90±.01	—0.87 ±.02	—0.83±.02
HE	0.31±.06	0.50±.05	0.24±.06	—0.11±.07	0.45±.06	0.27 ±.06	0.48±.05
HC	0.31±.06	—0.47±.06	—0.70±.03	—0 41±.06	—0.39±.06	0.15 ±.07	0.01±.07
HB	0.38±.06	0.25±.07	0.75±.03	0.62±.04	0.70±.04	0.03 ±.07	0.35±.06
HA	0.29±.06	—0.37±.06	—0.06±.07	0.54±.05	0.11±.07	—0.16 ±.07	0.10±.07
			4-lock Bolls				
FE	0.29±.06	0.36±.06	0.03±.07	0.02±.07	0.26±.07	0.18 ±.07	0.41±.06
FC	0.26±.06	—0.21±.07	—0.46±.05	—0.23±.07	—0.31±.07	0.16 ±.07	0.10±.07
FB	0.29±.06	0.00	0.46±.05	0.46±.06	0.60±.05	—0.01 ±.07	0.24±.06
FA	0.40±.06	— 0.28±.07	0.03±.07	0.08±.07	0.19±.07	—0.02 ±.07	0 20±.07
			Vegetative Branches				
EC	—0.31±.06	0.43±.06	0.52±.05	—0.15±.07	0.14±.07	—0.19 ±.07	—0.04±.07
EB	—0.58±.05	—0.40±.06	—0.47±.05	0.27±.07	—0.37±.06	—0.14 ±.07	—0.28±.06
EA	—0.14±.07	0.01±.07	0.06±.07	—0.26±.07	0.03±.07	—0.10 ±.07	—0.11±.07
			Fruiting Branches				
CB	0.41±.06	0.87±.02	0.84±.02	0.70±.04	0.69±.06	0.40 ±.06	0.35±.06
CA	0.38±.06	—0.01±.07	—0.14±.07	—0.26±.07	0.01±.07	0.13 ±.07	—0.15±.07
			Height				
BA	—0.44±.06	0.01±.07	0.01±.07	0.33±.06	—0.10±.07	—0.29 ±.06	—0.08±.07

*Where regression coefficients were of opposite signs and, of course, small, no r was calculated.

Not as much of the variation has been accounted for for weight of boll as for yield. Still $R_{L.HFECBAX}$ ran from 0.83 in College Acala No. 2 to 0.94 in Russell's Big Boll. This means that only 69% of the variation in the former and 88% in the latter variety has been accounted for.

For number of 5-lock bolls $R_{H.FECBALX}$ ran from 0.94 to 0.99, which is very uniform for all varieties, although not quite so uniform as the $R_{X's}$.

For all other characters the variation of the varieties with respect to the R's was not so uniform. This is to be expected, as we are dealing with varieties of different origin which were developed by different breeders. The ideals and breeding process of the different breeders might very easily account for the difference of these R's. Also, these latter may be more variable characters due to their heritability. Such factors or genes causing the expression of these characters may be more specific as regards certain characters. Further, a wider range of expression of certain genes might cause such variation. Linkage, or multiple factors causing more variable genotypes, might be the cause of such varietal differences.

As regards yield, and yield is the important character of all these eight characters, it can be said then, that it would be a waste of time for a cotton breeder to bother with any additional characters other than those shown in Table 1. Later those single characters most correlated with yield will be shown

PARTIAL CORRELATIONS

In Table 2 will be found the partial correlation coefficients of all the eight characters of each of the seven varieties, one with the other, and holding constant the other six characters.

In Table 3 are given the simple correlation coefficients between all characters for all seven varieties. These coefficients are placed here for convenience of comparison with the partial coefficients as given in Table 2.

YIELD AND WEIGHT OF BOLL

It is to be noted that $r_{XL.HFECBA}$, or the correlation between yield and weight of boll, $r_{XH.LFECBA}$, or correlation between yield and number of 5-lock bolls, and $r_{XF.HLECBA}$, or correlation between yield and 4-lock bolls, are high for all varieties. This is easy to understand when it is remembered that yield is weight of boll times total number of bolls and that four- and five-lock bolls make up the total number of bolls. Also, the simple correlation coefficients

TABLE 3.—*Simple correlation coefficients of seven cotton varieties between 12 characters of the plant, seed, and lint.*

Correlation	College Acala No. 1	College Acala No. 2	Young's Acala	Rogers' Acala	Okra Leaf Acala	Russell's Big Boll	Lightning Express
XL	0.61	0.58	0.32	0.40	0.53	0.44	0.59
XK	—0.07	0.02	—0.001	—0.05	0.22	0.16	0.05
XI	—0.26	—0.41	—0.27	—0.32	—0.20	—0.26	—0.08
XH	0.89	0.83	0.76	0.90	0.78	0.87	0.86
XG	0.95	0.93	0.83	0.91	0.94	0.89	0.97
XF	0.48	0.43	0.33	0.22	0.75	0.23	0.86
XE	0.65	0.49	0.43	0.43	0.66	0.54	0.46
XD	0.74	0.64	0.48	0.58	0.74	0.67	0.63
XC	0.45	0.48	0.33	0.50	0.58	0.46	0.33
XB	0.30	0.34	0.39	0.36	0.61	0.50	0.47
XA	0.16	0.33	—0.05	0.14	0.11	—0.10	0.12
LK	0.01	—0.11	0.21	—0.01	0.40	0.24	—0.01
LI	—0.06	—0.27	—0.09	0.01	0.12	—0.31	—0.02
LH	0.41	0.35	—0.03	0.29	0.43	0.17	0.47
LG	0.42	0.23	—0.15	0.08	0.30	0.03	0.45
LF	0.12	0.09	—0.20	—0.33	0.10	—0.29	0.35
LE	0.41	0.33	—0.11	0.06	0.20	0.26	0.20
LD	0.51	0.30	—0.09	0.03	0.28	0.36	0.36
LC	0.30	0.16	—0.07	0.01	0.30	0.29	0.24
LB	0.33	0.12	—0.21	0.02	0.36	0.12	0.28
LA	0.33	0.57	0.48	0.58	0.54	0.22	0.39
AK	—0.18	0.001	0.06	—0.13	0.25	—0.24	—0.004
AI	—0.22	—0.13	0.06	0.15	0.06	—0.25	—0.01
AH	0.05	0.07	—0.25	—0.04	—0.001	—0.28	0.02
AG	0.10	0.13	—0.23	—0.07	—0.01	—0.22	0.07
AF	0.15	0.12	—0.08	—0.12	0.01	0.05	0.11
AE	0.12	0.05	—0.18	—0.16	—0.10	—0.16	—0.01
AD	0.20	0.15	—0.31	—0.14	0.0001	0.10	—0.07
AC	0.17	0.23	—0.29	—0.06	0.03	—0.02	—0.07
AB	—0.05	0.18	—0.35	—0.05	0.05	—0.34	—0.03
BK	0.19	0.23	—0.09	—0.07	0.25	0.22	0.23
BI	0.64	0.17	0.06	0.13	0.16	0.16	0.48
BH	0.31	0.39	0.61	0.43	0.62	0.58	0.51
BG	0.26	0.52	0.68	0.51	0.56	0.50	0.45
BF	0.01	0.26	0.13	0.15	0.45	—0.04	0.37
BE	—0.07	0.10	0.16	0.36	0.32	0.17	0.10
BD	0.23	0.57	0.62	0.67	0.58	0.50	0.44
BC	0.37	0.83	0.66	0.68	0.78	0.54	0.48
CK	—0.001	0.13	—0.11	0.06	0.34	0.14	—0.10
CI	—0.24	—0.37	—0.60	—0.50	—0.12	—0.59	0.37
CH	0.42	0.37	0.23	0.41	0.45	0.41	0.28
CG	0.41	0.61	0.22	0.64	0.61	0.36	0.34
CF	0.18	0.45	0.09	0.36	0.48	0.05	0.31
CE	0.07	0.28	0.45	0.32	0.30	0.08	0.08
CD	0.75	0.76	0.91	0.90	0.77	0.83	0.80
DK	0.03	0.13	—0.16	0.04	0.21	0.15	—0.11
DI	—0.54	—0.72	—0.72	—0.60	—0.60	—0.81	—0.48
DH	0.67	0.55	0.43	0.53	0.63	0.62	0.57
DG	0.70	0.72	0.52	0.65	0.64	0.57	0.63
DF	0.38	0.40	0.15	0.27	0.52	0.06	0.56
DE	0.73	0.83	0.73	0.70	0.73	0.60	0.46

TABLE 3.—*Concluded.*

Correlation	College Acala No. 1	College Acala No. 2	Young's Acala	Rogers' Acala	Okra Leaf Acala	Russell's Big Boll	Lightning Express
EK	0.04	0.01	—0.15	—0.03	0.05	0.12	0.03
EI	—0.53	—0.82	—0.52	—0.52	—0.54	—0.45	—0.26
EH	0.57	0.51	0.36	0.37	0.73	0.54	0.50
EG	0.64	0.56	0.46	0.46	0.62	0.51	0.52
EF	0.34	0.19	0.10	0.28	0.38	0.03	0.42
FK	—0.27	—0.08	0.01	—0.10	0.13	—0.20	0.02
FI	—0.31	—0.33	—0.06	—0.28	—0.09	—0.05	—0.19
FH	0.17	0.05	0.03	—0.08	0.27	—0.01	0.57
FG	0.51	0.56	0.57	0.51	0.85	0.38	0.90
GK	—0.08	0.08	—0.12	—0.09	0.16	0.11	0.05
GI	—0.27	—0.50	—0.25	—0.33	—0.21	—0.11	—0.11
GH	0.91	0.80	0.97	0.83	0.67	0.91	0.85
HK	0.02	0.11	—0.12	—0.04	0.12	0.22	0.05
HI	—0.20	—0.32	—0.20	—0.23	—0.26	—0.22	0.01
KI	0.11	0.10	0.14	—0.12	—0.01	0.005	0.37
N	0.95	0.86	0.96	0.92	0.86	0.93	0.98

run high for these characters, yield with 5-lock bolls and yield with 4-lock bolls, even though not nearly so high as the partial correlation coefficients.

It is desired here to call attention to some work done by the writer while at the Texas Station on 16 varieties of cotton where the simple correlation coefficient of yield and 5-lock bolls were uniformly high for all varieties. In this experiment, yield was the actual yield of lint per plant (4).[5]

It is to be noted that $r_{LH.FECBAX}$, or correlation coefficient of weight of boll and number of 5-lock bolls holding the other six characters constant, and $r_{LF.ECBAXH}$ are high negative correlations for all varieties. In other words, the higher the weight per boll the lower the number of bolls. In practice this is understood to be so. All small-boll varieties bear larger numbers of bolls than do the Texas big-boll varieties. In breeding cotton we are looking constantly for an individual which will produce many bolls and will at the same time have a big boll. Russell's Big Boll showed the highest correlation of all these varieties with respect to weight of boll and 4-locks as well as with 5-lock bolls. This variety had the highest mean weight per boll, as noted earlier in this paper. Lightning Express, an eastern variety, also showed a good negative correlation with respect to the characters mentioned and, as has been said, Lightning Express had the smallest mean weight per boll of all the varieties.

[5] For correlations of other characters in cotton see Kearney (3).

It is to be noted further that Russell's Big Boll had next to the lowest mean number of bolls per plant and Lightning Express the highest number of bolls.

Also, a high fruiting variety of cotton is usually thought of as one that is close-jointed. There was only 0.0014±.0028 difference in mean close jointedness of Russell's Big Boll and Lightning Express. From this then it appears that Russell's Big Boll has just the same capacities for producing a large number of bolls as did Lightning Express. Why this difference, then, in number of bolls? It could not be that Lightning Express repels insects, because in the upper Rio Grande valley there were hardly any insects that bothered cotton in 1928, as the boll weevil does not exist there and the cotton flea is not known.

The mean yield of lint per plant of Russell's Big Boll was 45.07±1.47 and of Lightning Express 59.38±2.25 grams. Neither of these two varieties is the highest nor lowest, as was noted earlier in this paper, but Lightning Express shows a lead over Russell's Big Boll of 14.31±3.51 grams, which is a fairly significant difference. In other words, Lightning Express set more than enough bolls to make up for its deficiency in weight per boll.

The ability of Lightning Express to set a larger number of bolls than Russell's Big Boll is not due then to its bigger plant capacity, but must be due to an inherent vitality or vigor which causes it to hold and produce more food and thereby hold a large percentage of fruit.

Returning now to the desire of the plant breeder to obtain a high-yielding variety of cotton and knowing that a high-yielding cotton would be one that had a high weight per boll along with the capacity to set a high number of bolls, Just what do these negative correlations between weight per boll and the number of 4-lock or 5-lock bolls mean?

If we were measuring the direct expression of not too closely linked genetic factors, the correlations would probably reverse themselves in one of the varieties, but in all varieties we have a negative correlation which seems to show that we are measuring a physiological condition. Stated in simple terms this would mean that in each variety it has certain capacities to produce lint and the higher the weight per boll the lower will be the number of bolls.

The above facts tend to relieve the cotton breeder in that he may still be able to combine in ample proportion the two important things that make up yield of lint in cotton. There must be certain definite sets of genes for these characters, i.e., weight per boll and number of bolls. So far we have not measured their degree of genetic association and they may be independently inherited, and such we must consider them until they have been proved to be otherwise. If so, the cotton breeder can still cross plants having high weight per boll and plants having high number of bolls in the hope of fixing the combination in a variety.

It is to be noted that the highest class in weight per boll was 4.25. This occurred in two varieties, College Acala No. 2 and Russell's Big Boll. Also, the highest class as to total number of bolls was 75 bolls per plant, in Lightning Express. The partial correlation coefficient between weight per boll and number of 5-lock bolls, as well as number of 4-lock bolls, shows high negative correlations within each variety. Since the partial coefficient measures the true relationship between two characters with the other involved characters held constant, would it not be possible to combine in a strain of cotton a high weight per boll with a capacity to set a large number of bolls by inter-varietal crosses, or specificially, by crossing Lightning Express and Russell's Big Boll? It should be understood, of course, that the highest individuals as to each character would be the ones to cross.

FURTHER RELATIONSHIPS INVOLVING NUMBER OF 5-LOCK BOLLS AND NUMBER OF 4-LOCK BOLLS

By referring to Table 2 it is shown that a high negative correlation exists between number of 5-lock and number of 4-lock bolls. The coefficient of correlation or $r_{HF.ECBAXL}$ between these characters runs from —0.74±.03 in Young's Acala to —0.92±.01 in College Acala No. 1, showing that with high number of 4-lock bolls there was a low number of 5-lock bolls It might be well to state here that there is in practically all upland varieties of cotton a greater number of 5-lock bolls than 4-lock bolls, with an occasional 3- or 6-lock boll.

From Tables 2 and 3 five-lock bolls seem to be correlated to some extent with height. The partial correlation coefficeint ($r_{HB.CEFAXL}$) runs from 0.25±.07 in College Acala No. 2 to 0.75±.03 in Young's Acala, with the exception of Russell's Big Boll which shows no correlation. However, even Russell's Big Boll shows a strong simple correlation coefficient, $r_{BH} = 0.58 \pm .05$.

The number of 4-lock bolls shows significant correlations with height of plant in three varieties, while in two others some correlation is shown and in the other two no correlation whatsoever is shown.

The relationships of number of 5-lock bolls with number of fruiting branches, or $r_{HC.EFBALX}$, run from —0.70±.03 to 0.31±.06.

The correlation coefficients of 4-lock bolls and number of fruiting branches are very variable. The simple correlation coefficient of the above characters (r_{PC}) are about as variable as the partial correlations, but the $r_{HC's}$ are fair correlations in most varieties.

RELATIONSHIPS OF OTHER CHARACTERS

As to the relationships of the characters not discussed above, inspection of Tables 2 and 3 will show that they vary considerably from one variety to the other. The breeding of one variety has made one relationship exist and in another variety with a different breeder another situation is found. It would be a waste of time to discuss them in detail here. However, some mention of them will be made in the summary.

RELATIONSHIP OF PARTIAL AND SIMPLE CORRELATION COEFFICIENTS

By comparisons of Tables 2 and 3 it will be noted that in some cases the partial correlation coefficients are similar to the simple correlations, while in other cases they nearly reverse themselves. Also, in other cases, the partials were very much smaller than the simples. The correlation between partials and simples was calculated and found to be 0.50±.04. This is a significant correlation but means that the simple coefficient would be reliable in only about 25% of the cases.

SUMMARY

A biometrical analysis of seven varieties of cotton is reported on the 1928 crop at State College, New Mexico, in the upper Rio Grande Valley. The differences in type and variability of these varieties as to 12 different characters are briefly discussed.

Multiple correlation coefficients are shown involving eight different characters, thereby measuring the combined correlation of the seven characters on the eight. Eight of these R's per variety are shown. The characters, weight of lint per boll, percentage of lint, number of 5-lock bolls, number of 4-lock bolls, number of vegetative branches, number of fruiting branches, and height upon yield, gave a uniformly high multiple correlation for all varieties, running from 0.96 to 0.99. The correlation of the seven characters upon number of 5-lock bolls ran from 0.94 to 0.99. $R_{L(\text{weight per boll}).\,ABCEFHX}$ ran from 0.83 to 0.94. Also, $R_{F(\text{number of 4-lock bolls}).\,LABCEHX}$ ran from 0.82 to 0.97. The other R's were not so high and $R_{A(\text{per cent lint}).\,BCEFHXL}$ was not of any significance.

It can be said in cotton breeding that if the above-mentioned characters are taken into account, we shall have all of the characters associated closely with yield.

Yield is made up of number of bolls and weight per boll and, of course, strong partial correlation coefficients are found. However, number of bolls is more closely associated with yield than weight of boll. Usually the varieties having the lowest weight per boll show the poorest correlation of yield and weight per boll. Weight per boll and 5-lock bolls, as well as weight per boll and 4-lock bolls, were highly negatively correlated. The fact that both 4-lock and 5-lock bolls were correlated with weight of boll shows that number of bolls would be highly correlated with weight of boll. A variety producing a high weight per boll and which has the capacity for producing a large number of bolls should be the aim of the cotton breeder.

Number of 5-lock bolls and number of 4-lock bolls are shown to be negatively correlated, the coefficient ($r_{HF.ECBAXL}$) running from —0.74±.03 in Young's Acala to —0.92±.01 in College Acala No. 1. This is nearly the reverse of what the simple correlation coefficient shows.

Results show that 5-lock bolls are correlated to some extent with height, with the partial coefficient ($r_{HB.ACEFLX}$) running from 0.25±.07 in College Acala No. 2 to 0.75±.03 in Young's Acala. For number of fruiting branches and height fair positive partial correlations were obtained, the coefficients running from 0.35±.06 in Lightning Express to 0.87±.02 in College Acala No. 2.

As shown by the partial correlation coefficients, the other characters studied were not uniformly correlated with each other. In some cases negative correlations were shown in some varieties and positive correlation in others. Those showing the latter situation are as follows· Yield with vegetative branches, yield and fruiting branches, and yield with percentage of lint; number of 5-lock bolls with number of fruiting branches and with percentage of lint; number of 4-lock bolls with number of fruiting branches; number of vegetative branches with number of fruiting branches and number of vegetative branches with height; height and percentage of lint; 4-lock bolls and percentage of lint; and fruiting branches and percentage of lint.

Those characters that showed no correlation in some varieties to some positive correlation in other varieties are as follows: Weight of boll and vegetative branches; weight of boll and height; 5-lock bolls and vegetative branches; 5-lock bolls and height; and 4-lock bolls with vegetative branches.

Yield and height were correlated from 0 in two varieties to —0.77 in Rogers' Acala.

Vegetative branches and percentage of lint did not show a significant correlation in any of the varieties.

The simple correlation coefficient was calculated between the simple coefficients and the partial coefficients and found to be 0.50±.04.

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INITIATING AND EXECUTING AGRONOMIC RESEARCH[1]

E. W. ALLEN[2]

Every research project is an investment, on the part of the individual and the institution, and as such it involves a risk. Whether it will return dividends, and when or how much, is problematic but not entirely beyond estimate. In some cases the risk is quite speculative; in others it is sound and conservative. The degree of security depends primarily upon the leader, his scientific attitude, the depth of his motive, and his conception of the problem and its requirements.

A research project ought to commend itself in the prospect it merits as well as in the desirability of the thing sought. The prospect is indicated by the purpose or objective of the project and the means sought to attain it. If it can not qualify under reasonable examination, it may be regarded as an undue risk.

There is advantage in looking at the matter from this materialistic point of view, for there sometimes is disposition to regard lightly the obligation which a project implies, and to overemphasize the uncertainties of the outcome in research. The weighing of expectations is considered by some as unreasonable and in a sense unscientific, because of the very nature of research. But a project can not succeed unless it deserves to; and the measure of its prospect is a proper matter for institutional concern. The proposal originates with the leader, but acceptance or continuance is an administrative responsibility.

Membership on a research staff implies more than doing something; it implies doing the desirable things in the right way. For a project is part of a program, often a link in it. It is expected to be scientifically sound no matter how practical its aim. Not all "research" is necessarily good. Merely because it is dignified with that name does not make it commendable or worthy of support. I do not intend to speak with disparagement when I say that I know of no field where there is greater opportunity for misdirected effort and waste than in the field of experiment, unless there is well prepared planning with discriminating follow up. Waste in the sense of partial failure is inevitable; it is inexcusable only when it continues indefinitely because of inattention or inadequate conceptions and standards.

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[1] Contribution from the Office of Experiment Stations, U. S. Dept. of Agriculture, Washington, D. C. Presented at the annual meeting of the Society held in Chicago, Illinois, November 14, 1929.

[2] Prior to his death on November 11, 1929. Chief of the Office of Experiment Stations. This paper was read for Dr. Allen by H. L. Knight of the Office of Experiment Stations.

Agronomy long has been one of the leading subjects at the experiment stations. Hence it is not surprising to find that according to last reports there are some 2,300 projects relating to crops, soils, and fertilizers. This constitutes practically a third of the total number of station projects. It omits many in related fields which bear directly on agronomic questions; and of course it does not include a large list of projects in the Department of Agriculture. But the figures show the prominent place the subject occupies in the programs of the experiment stations, and this prominence is growing. Since 1920 the number of station projects in soils, fertilizers, and field crops has increased fully 50%. No other subject among the older branches has grown so fast.

If we examine into the character of these projects, we find that fully half of the total number are of the conventional type and do not share in the great advance in agronomic research. They consist of tests and trials of various kinds, made under local field conditions by means of standardized methods, and for the most part represent little ingenuity in framing a question or planning the approach. The element of inquiry or the motive to get general facts is little in evidence. Indeed, some of them are not far removed from local demonstrations.

Let me say, lest I be misunderstood, that in many respects research in agronomy has grown in intensity and originality as few other subjects have. It has made great scientific progress, and is building up a body of coordinated knowledge which supplies a broad basis for theory and practice. Because of this significant progress, gradual development naturally is expected which will extend to all its branches. It is the more surprising, therefore, that parts of the work seem to mark comparatively little advance in method or outlook, but to considerable extent have become conventionalized to a degree which suggests the work of the technician quite as much as the investigator. The scope of this type is so large and the effect on the whole body of agronomic work so far-reaching as to merit frank discussion within the circle.

Judging from their continuance, variety and culture experiments with a wide range of crops, seedbed preparation, rate and date of seeding, and the like, have lost none of their earlier popularity, and without change of approach they seem destined to be with us for many years to come; while the comparison of cut vs. uncut potatoes and pieces of different size for seed goes steadily on, though perhaps not as live a subject as 25 years ago.

A good deal of work designated as "breeding studies" consists merely in field selection, and does not embrace the opportunity for studies of inheritance or other breeding principles. Some projects on weed control attempt to deal with the whole problem and hence do not get into it very deeply.

The so-called "fertility needs" of specific crops are still being "determined" in field experiments without the aid of further refinements, and apparently without finality of results, and the comparison of fertilizing materials and forms shows little diminution. Nor do the methods always meet modern ideas of good technic, for common everyday field trials with fertilizers are still being proposed in which checks and replications are quite inadequate to the standards set up by this Society. Several recent ones provided for no replication of treatments, and only a single untreated plat to serve as check on the lack of uniformity in the field. The explanation offered in one instance was that the area available did not permit of these checks. I fear such inadequacies may be a reason for the self-perpetuation of such experiments.

Then there are the long-time fertilizer, rotation, and soil fertility experiments, in which the purpose to see what actually happens is not extended far beneath the surface. Periodic summaries are supposed to record the progress, if not to show advance toward conclusions. According to prevalent views, these should continue for a period equivalent to the productive life of a worker, and if in the meantime the soil under some of the treatments gets quite out of condition the crop will reflect it, so why seek further?

You will understand that I am not disparaging work which is elementary and of practical aim, or of the types referred to if it is the best that can be done with the light at hand, but I wonder if it is. Testing and comparative field trials represent the pioneer stage; too often such work is not transitional but seems to be both the beginning and the end. Unquestionably there is, and will continue to be, a place and a need for simple tests which are exploratory and designed to meet temporary needs, but these are not research in a true sense, and an investigator can not afford to exhaust himself by such efforts or fail to be stimulated to get deeper into the real problem when the opportunity offers.

For the researcher in agronomy is more than a tester, a "trouble shooter," or even a technical adviser. His work is creative; it seeks permanent values, the boundaries of facts—not alone for his own use but in order that the knowledge they give may make others more intelligent and resourceful. If his work ever comes into large general use, it will be because he has developed some basic facts which can be stated so that they can be used intelligently and modified as circumstances require. This means understanding of these facts and their relationships based on the conditions under which they are obtained, which is part of the modern program. Results which merely give uninterpreted information and teach little of a general nature do not bring us much closer to the life activities and requirements of crop plants or of factors applicable in good farming systems.

I realize that such a characterization of work which comprises so considerable a part of the agronomy program may seem harsh and unappreciative to some, and I assure you it is not made lightly or in a spirit of impatience. But the exploratory stage has been passed in many cases; testing has been superseded by investigating as the line of advance. To be soundly practical and suited to the changing needs, the experimental work must grow. It is necessary to take account of causes as well as to note effects. I am confident that without sacrificing any of the practical interest or value, work of this type might often be made more scientific and enlightening by refinements and additions that would reflect the deeper motive to learn. It will not do, of course, to let the practical character of a problem be the cloak for what President Eliot once referred to as an "economy of intellectual effort," or to overlook the lesson that short cuts are ery often the long way around, and in the meant ime may be misleading.

In the earlier days of experimenting, the subjects attacked often seemed simple and capable of solution by a few comparative trials. Further work showed, however, that the matter was more complex than originally appeared and did not yield so readily to the conventional type of work. So finally it was necessary to begin again, with the new vision, and not only to improve the technic but to employ other means to reach the desired end. This is a common experience, and the course deserves no criticism if the signs are recognized as they appear.

The notable change in agronomic work in recent years which has contributed so much to its advance has been in the objective and the motive, as well as in the improvement of procedure. In this change we are passing from the general to the particular, from fields of work to topics narrowed to concrete and limited questions, better understood and more directly approached. The research ideal at the present stage is clarity of purpose, procedure specially devised to meet the purpose and eliminate chance to the *n*-th degree, and interpretation of results in the light of statistical analysis.

The inauguration of an investigation at this time is quite a different matter from what it was years ago. The background is so much larger that far less blind speculation is involved; and on the other hand, the status of knowledge implies the need for greater concentration of the objective and more imagination, since every undertaking aimed at further knowledge needs to have back of it an idea.

First of all, then, it is right to expect that a new project will be definite and limited. It is not a field of work, although it is related to one; and it represents something that needs to be done—otherwise it would be inopportune. The worker ought to be clear in his mind as to what he is seeking and just why he is undertaking it.

Second, the new project is a reasoned, carefully considered undertaking, subjected to searching criticism and suggestion. The means are adjusted to accomplishing the desired ends, as far as can be determined in advance, and will be modified as circumstances develop.

Third, it depends on what has gone before—the background on which it is to make its contribution, and is designed to fit constructively into the picture. All research rightfully depends on what has preceded it. Even though it blazes new trails, its conception lies in what has been accomplished, i.e., in the status of knowledge, or what this suggests. If we are to stand on the shoulders of the past in projecting new investigation, we must use not only the results but the ideas which may be developed out of them.

A research project should start where others have left off, or where apparently their work has ended. Repetition and replication may be warranted where aimless duplication is not, but blind repetition without any definite or justified reason and devoid of any new idea is a reflection on imagination and individuality. Confirmation usually is more searching and direct than duplication. The present need is not for more work of the same kind done in the same way, but for more work by advanced means and outlook.

There is a vast background of empirical facts and results on which to build. And beyond this, a great deal has been learned about the factors of plant growth and adaptation, the influence of such factors as light and moisture, soil reaction and colloids, and the means of measuring response and the nature of resistance. It is not necessary to rely upon the cruder types of experiment or to wait on their uncertain answers.

The procedure of a new project indicates the general line of attack and the means to be employed. The details will be subject to revision from time to time, for the course of investigation depends on the results and what they indicate. On the analysis of them will depend judgment as to the adequacy or effectiveness of the means employed, the necessity for repeating or enlarging experiments, and the type of determinations which are needed from stage to stage.

Research is forward looking, and it gathers strength as it goes. An investigation which does not indicate whether or not the inquiry is on the right track or suggest the succeeding steps is proceeding in the dark. Unless the results are calculated and studied currently, the basis for further investigation is wanting and the hazard is increased.

The basis of research is the accumulation of evidence; its method is the means by which the needed evidence is secured. Ascertaining what data are essential, devising means of securing them, and testing them as to their applicability and sufficiency is a large part of research. The aim naturally will be to secure evidence that is to the point, is as positive as possible, and sufficiently extensive to enable critical analysis. Concentration on this will hasten the progress.

Since the nature of a problem governs the kind and character of the essential data, it is important that the problem be understood as fully as possible at the outset and developed as the work progresses; otherwise effort may be unfruitful. Except in entirely new lines, there is considerable basis for judging the nature and content of a problem at this time, as shown by the research and speculation of other, which needs to be mastered.

In most subjects successful research is dependent not only on its own advance, but on the advance of related sciences. This is especially the case in a subject like agronomy. Regard must be had for the inevitable sequence in research to unravel a problem. Yet ends are frequently sought which are unattainable because some branch of science essential to their solution is not taken into account, or has not produced the knowledge or supplied the ideas on which a working hypothesis can be framed. We have only to recall that understanding of soil fertility waited long on the development of soil bacteriology, and progress is still dependent on it. Other manifestations of the soil we now know depend on recognition of the part played by colloids. The progress of physical and biological science makes attainment more possible; hence the importance in such a complex field of breadth of vision and interest.

To learn to think scientifically is one of the primary requisites. It took man a long time to learn what scientific thinking meant, and then to think constructively, to weed out the true from the false, the useful and applicable from the indiscriminate, and to find ways of advancing the boundaries. The successful investigator must be on the keen lookout for manifestations that offer a new idea. To that end he will cultivate a mind alert to detect the unusual in the usual.

Above all things, the searcher in science needs to avoid adherence to routine. Instead, he must think and plan and coordinate. Experiments involve many operations which are routine, but the thinking about them and the place they fill need not be routine. When routine gets the upper hand, critical analysis and constructive thinking pass into the background. Routine experiments which do not mark advance not only occupy time and space, but ultimately may hold the maker down to their level instead of helping his standards to grow.

Doing and thinking go hand in hand in research. The doing is more or less mechanical even though skillful. The thinking guides the doing and interprets the result of it. To continue to conduct experiments after they have failed to shed light and need to be modified may be to add to the confusion. What one ultimately gets out of an investigation is dependent on what he puts into it—not in routine but in study and speculation. The product is a measure of individual application and of ability "to think without confusion clearly."

The investigator ought to dare to adventure—to doubt, if there is reason for it, to speculate and evolve a theory, and then to make an excursion planned to test it. It is by that means that new avenues are opened and new areas of fact developed. The work should be a live and aggressive effort, not only at the outset but in its continuance from stage to stage. As far as possible, individuality ought to be put into it—some originality of approach or execution or interpretation. While it is admitted that much testing and comparative work remains necessary, new work need not be wholly conventional or standardized in its concepts and procedure.

For his research to be progressive, the investigator needs to maintain within himself the elements of growth. The initial training is not always sufficient to meet the changes of time. One can easily become an unprogressive back number, especially in his thinking. So it sometimes is important for him, in order to keep fresh and keen, to go outside of himself and his immediate resources. An advanced course in physical chemistry, physiology, or genetics, or other highly specialized subject, may be just what he needs to whet his imagination or expand his range of thinking about his project. It is for such purposes of improvement and growth that sabbatical leave is designed.

And such broadening, stimulating influence promotes cooperation and coordination, the viewing of research less individually but more from the standpoint of the subject itself and its systematic advancement. The advantage of greater system in agronomic research, the logical following out of certain lines of advance through the various specialties involved, is more and more apparent. This implies, of course, ordering one's research in relation to that of others, either through coordination or conscious participation in organized effort on live topics, in order to develop these and to advance them rapidly. It contemplates fitting individual pieces of research into some common channels, with specialization in component features.

If we continue to wait patiently until free-hand, independent research has gradually supplied the essentials and filled the gaps to round out a subject, and until this knowledge is properly coordinated and reduced to practice, the final end may be long delayed. A recent writer[3] has referred pointedly to "the growing impatience of the intelligent layman with those specialists who continue to regard their compartments of knowledge as water-tight and self-sufficient."

With due appreciation of the advantage of specialization, it is apparent that a specialist in agronomy cannot afford to conceive his specialty too narrowly or limit his collateral interests too closely. Whether he is working on its problems independently or in cooperation, his work needs to be coordinated with other branches and features which may be equally essential, and these considered in their respective relationships to complex problems.

In conclusion, let me say again that these observations are not to be regarded as in any sense an attack or as minimizing the great advance in this field, but rather as a frank discussion of the subject with you. The vast change which has occurred in agronomic research should increasingly leaven the whole. Until this is the case, I believe you will agree with me that the need is less urgent for more money than it is for more effective use of part of the existing funds. Frank, critical discrimination might do much to relieve the stress of finances.

[3] Joseph Mayer in the "Seven Seals of Science." Page 7.

IS IT DESIRABLE FOR AGRONOMY TO TRAIN ITS OWN RESEARCH WORKERS?[1]

W. C. COFFEY[2]

My subject, which is stated in the form of a question, may be variously interpreted. Does it ask, is it desirable for agronomy to train its research workers wholly within agronomy? Or, does it mean wholly independent of agronomy? Or, does it ask whether they should be trained under the direction of agronomy or perhaps in consultation with agronomy?

As I begin to discuss this problem, what shall I say that agronomy is? I cannot discern that agronomy has any set definite boundaries as indicated by the manner in which it is organized in our various agricultural colleges. In one institution soils may be a part of agronomy and not in another. Some institutions include plant pathology, plant breeding, and plant physiology as a part of agronomy and others do not. I doubt if one could find a definition of the subject which practice in our educational institutions as a whole would support. I confess, too, that my own mind is not set with respect to what the definite boundaries of agronomy should be.

Again, what do we mean by training our research workers? I presume we refer to that training which occurs during the undergraduate and graduate years, but we must look upon training as a life process and if a research worker falls into the environment of agronomy, necessarily agronomy must have something to do with a part of his training.

To the degree in which agronomy is a science, I think all would agree that it is a biological science. I asked a friend, who is trained in plant science and who is working in that field but not as an agronomist, to give me what he regarded as an all inclusive definition of agronomy. Rather hesitatingly he said, "If I were to try to surround it with one all inclusive term I would say that it might be a matter of plant ecology which has very definite economic implications."

The phases of agronomy are so many that we cannot hope to train any one man to cope with them all on a level with the demands of modern research. But there are certain principles or fundamentals common to all its phases which should be mastered by its capable workers who are to be responsible wholly or in part for effecting solutions of problems and endeavoring to make these solutions yield some useful service in the realm of production.

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[1] Presented at the annual meeting of the Society held in Chicago, Illinois, November 14, 1929. Published with the approval of the Director as Paper No. 934 of the Journal Series of the Minnesota Agricultural Experiment Station, St. Paul, Minn.

[2] Dean and Director.

Aside from its economic implications, which are not to be waived aside as unimportant, agronomy is a biological science. All biological science is based upon chemistry, physics, and mathematics. These fundamental or basic sciences must underlie agronomy's attack which in various ways must deal with plant cell structure, behavior, and function. I would hesitate in attempting to name all the primary and secondary lines of sicence necessary to all the legitimate and desirable activities within agronomy. One could begin with more inclusive subjects, such as soils and fertilizers, but they require a knowledge of chemistry, physics, bacteriology, and geology. Or, one might mention plant growth, reproduction, and response, but he would have to include not only chemistry, physics, and bacteriology, but also statistics, taxonomy, genetics, physiology, pathology, and perhaps still other lines of work.

Our chief concern about the research worker in agronomy should not be whether or not agronomy should train him, but rather how should he be trained. It seems to me that he will need to know something about a number of lines of science, but he must be able to work in the terms of some one science which he will chiefly employ in his research. Therefore, while his training should be intense in one certain direction, it nevertheless should be basic and fairly broad. It is conceivable that some department of agronomy is broad enough and big enough to provide for the training of all of its workers, but such a happy situation is not very likely Every department of agronomy should be capable of conceiving of the fundamentals necessary to the training of their workers, however. If this is the case, agronomy might have much voice in directing their training, but not necessarily sole voice. But it is the duty of any particular department of agronomy, I believe, to know where, in its institution, or in other educational institutions, the best work and the best men to give the necessary training are to be found. And knowing this, its duty lies in the direction of heading its men who are being prepared for research work toward the best work and the best men giving it.

It is conceivable that some (not all by any means) of the most useful research workers may be trained wholly outside the agronomy fold. When suitable men so trained are located they come into the work with none of the inhibitions of the agronomist. It pays to bring men of this sort into the field. They may jar our orthodoxy, but after a time the happy discovery is made that they have freshened and sharpened the attack upon technical problems. Then, too, such men are occasionally worth bringing in because there are cross-over values from one field to another related field. And the surest way we have of getting these values is to draw in men whose experience has been foreign, but not too remotely foreign, to agronomy.

The training of a research worker does not carry through unless he has the power to make applications of truths or principles uncovered. As a worker he must have the ability to see his problem in its complex relationships, that is in relation to other problems peculiar to agronomy and perhaps to other fields; to organize his work with its bearings clearly in mind; to organize it so that he will not be lost in its details, but rather be able to see their significance and to analyze out their real and true value Since this is true, somewhere in his experience the agronomy researcher should grasp the needed agronomic attitude. For example, he may grasp this attitude in assigned field experience, or possibly laboratory experience, or in conference, or in class, but somewhere he needs to develop an appreciation of the difficulties he may have in integrating the factors affecting his problem. This is a contribution that may be expected from agronomy. No other department should be quite the equal of agronomy in training the research worker to have a respect for what the situations in the field can show him.

Whether or not the research worker is to be trained by agronomy, I am very certain that the man who acts as chief adviser to the graduate student preparing him for research has a great responsibility. When the prospective graduate student comes to him for a graduate's program, this adviser must, if he truly performs his duty, take time, even though it may involve a conference of from three to five hours, to determine what the interests and abilities of the man are, and to ascertain where the man wishes to go This is good procedure, of course, in the undergraduate world. And when the adviser has determined these things, then he should proceed to build the graduate student's program around his central purpose, but in so doing he should convince him that it should be builded on a broad and not on a narrow basis. If this procedure is followed, other values in addition to the comprehensive training are secured in most cases. I refer to the development of a spirit of enthusiasm for work in the man's own special line, and also a spirit of true cooperation with men in related lines. This is a matter worthy of serious consideration, for the specialists within agronomy must heartily cooperate amongst themselves and with men in related fields if a significant product, which can be utilized in practical applications, is to be secured.

RESEARCH IN REGIONAL PEAT INVESTIGATIONS[1]

ALFRED P. DACHNOWSKI-STOKES[2]

During the meetings of the First International Congress of Soil Science held in Washington, D. C., June 13 to 22, 1927, a Sub-commission was established for the study of peat land and its uses. A special committee was appointed to develop an international program for the various lines of research and methods of study which touch upon the subject of peat.

The area of peat in the United States, exclusive of its possessions, is estimated to be over 100,000,000 acres, while that of Eurasia is believed to aggregate more than 200,000,000 acres. The acreage of peat deposits in the southern hemisphere of the world has not yet been determined or properly investigated and therefore cannot be considered at this time.

It is well known that deposits of peat represent one of the chief sources of raw organic material for agriculture and certain related industries. In addition to being one of the great undeveloped land resources, they constitute the indispensable record upon which to base our views and ideas regarding plant life and changes in its environment. Both a far-sighted view and international cooperation are imperative to clear up the obstacles with which the study and utilization of peat land are confronted. Excellent as has been the work in peat investigations in European countries through many years, it is obvious that in considering the great future importance of American and Eurasian peat lands, something more can and should be done along the lines of organized effort and collective thought.

In this program the Sub-commission recognizes the need of basic facts in the selection of peat lands for different purposes, including the conversion of raw peat materials into a commodity of commerce, for the protection of peat areas from destructive agencies, and for the improvement of yields in quantity and quality. Accordingly, the Sub-commission proposes in its program to promote the correlation of such work with similar research by member countries of the International Society of Soil Science. It welcomes the fullest cooperation on the part of individual investigators and different states and countries, and every effort is being made to coordinate in a practical way what experiment stations and extension services are doing.

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[1] Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Presented at the annual meeting of the Society held in Chicago, Illinois, November 15, 1930.

[2] Physiologist.

The chief function of the International Peat Committee and the National Peat Sections will be, therefore, to bring about friendly and closer cooperation between research workers in the several branches in peat investigations, and to stress the general adoption of definite concepts and uniform methods in a far-reaching program.

PROPOSED PROGRAM

Below is outlined a provisional program calculated to meet the requirements of different states and of individual workers and to produce results in peat investigations readily comparable with one another.

BOUNDARIES OF PEAT LANDS

There is the obvious duty, first of all, to arrive at some agreement for defining the boundaries of peat lands. In place of the numerous local methods at present in use, it is suggested that the Congress in Russia consider the adoption of an international basis and scale for delimiting boundaries and recording distribution of different areas of peat. Our work will be greatly facilitated if the term "peat land" or "moor" is applied to an accumulation of plant remains, or the products of decomposing processes acting upon the parent organic material, that is dimensionally at least ½ meter (20 inches) thick, and ¼ hectar (1 acre) in area, with a content of mineral matter not exceeding 35%. Such restriction of this term by international agreement would prove useful for purposes of defining and mapping peat and muck deposits. Dimensionally limited in this manner, a survey of peat areas would make for precision in census statistics covering the available acreage and quantity of organic material for different uses. The scale recommended above would contribute to the improvement of field practices, and that large and increasing line of experimental and industrial work which depends on the proper selection of areas in fields differing more or less widely.

CLASSIFYING AREAS OF PEAT

Agreement on methods and technic for profile studies and for classifying areas of peat is most desirable.

At the outset there should be a clear understanding of the terms "peat" and "muck", so that differences of definition may not hinder discussion. In general, scientific usage the term "peat" denotes plant remains which are susceptible of exact botanical identification. It is convenient to distinguish peats derived from forests and woody shrubs, from sedges, reeds, "sawgrass" and "tule" marshes; from

Sphagnum and Hypnum mosses, and the mud-like gelatinous organic sediments that appear as suspensions in lakes and ponds. Saturation with water prevented access of air to the plant remains, stopped aerobic decomposition, and thus resulted in the preservation of the tissues of the original vegetation as layers of peat.

Muck, on the other hand, is a residual organic material produced by soil-making processes in the zone of weathering and oxidation above the water level. It is that portion of the surface which differs more or less widely and distinctly from the original parent layer of plant remains. In the earlier stages of aerobic activity the cover of muck is very thin and there is no fixed line between peat and muck. The residual layer increases in thickness as decomposition proceeds, varying in depth with fluctuations of the water level, with cultivation, and with climate. Muck is likely to contain a larger proportion of mineral matter than peat as it passes through more advanced stages of decomposition to the final transformation into humified soil organic matter. In many cases only black mineral soils with a high humus content remain today to suggest the former location of drained or cultivated areas of peat and muck. On this basis there can be no question of the occurrence of different kinds of muck corresponding to different types of peat, although there may often be mixtures and stages that are susceptible of exact identification and measurement only in the laboratory.

The greatest practical advantage derived from the botanical identification of peat layers is, that it furnishes a classification of peat and a procedure for the major grouping of the peat lands of the world, comparable to the present system used in this country for mineral soils.

In order to be comprehensively classified, peat lands must be differentiated on the basis of a few outstanding criteria. The inherent structure of peat lands has been found most helpful in the systematic examination of the floral and pollen records of peat deposits. The character of the stratigraphy determines in a great measure the kind of commercial operation and even more the industrial uses of different kinds of peat. Stratigraphic differences between peat lands should be given serious consideration in any broad scheme of peat soil classification that will be capable of application in the field and will meet the requirements of and cooperation with the Fifth Commission of the International Society of Soil Science. Areas of peat having the same number and sequence in the chief layers of peat, together with a similar range of morphological features in the vertical section, showing close similarity in all respects except in the texture of the surface layer, and coordinating with certain major environmental conditions from the surface down to the underlying basal mineral substratum, should constitute a peat profile group designated as series.

On the basis of texture or class of peat at the surface, each series would consist of one or more peat soil types. In this connection, the term "texture of peat soils" refers to the chief classes of peat materials which are designated as woody, fibrous, and sedimentary peat. The materials are derived from distinctive groups of natural vegetation which on the whole are ecologically related throughout Europe and America and hence reflect corresponding grades or sizes of plant remains. Degrees of decomposition may be indicated on a scale of 5 or 10 divisions as described elsewhere in an earlier article. Units of texture should be designated by the relative content of the various sizes or grades of peat and the mixtures intermediate between them, as for example, finely fibrous (radicellate) sedge peat, coarse fibrous moss peat, fine granular saw-grass muck, sedimentary fibrous reed peat, woody fibrous heath peat, etc. Accordingly, each type unit of peat soil would be defined in terms of series and texture characteristics, and following the nomencalture of the U. S. Soil Survey, the several series and type units of peat soils of any state or country would be designated by geographic names or by the locality where the series unit was first identified and described.

It cannot be too strongly urged that vertical profile features be expressed by an international method. The additional field work involved is not unduly heavy when the advantage to scientific unity and coordination of profile analyses is taken into account. Areas of peat present decidedly different problems from those possessed by mineral soils, and they justify the amount of time and the trained personnel which this phase of field work requires for properly correlating and harmonizing results.

It is proposed that a central office be established for the collection, identification, and exchange of peat materials, and for the preservation of photographs, diagrams, maps, and rare or unusual organic remains fossilized in peat deposits, the paleobotanical material to be published from time to time with appropriate illustrations and definitions, for use in all branches of peat investigations. The consideration of establishing uniform methods for stratigraphic and morphologic studies has been placed in the hands of a branch committee on peat land stratigraphy.

GROUPING ON REGIONAL BASIS

In the progress of peat investigations it has been found necessary to construct some kind of a provisional scheme for grouping peat lands on a regional basis in order to be able to coordinate all phases of field and laboratory work. The term "region" refers to areas of peat in which the formation of peat deposits is predominantly alike both in botanical composition and in general environmental conditions but different from the predominant peat accumulations in some other region.

In the United States peat lands may be broadly divided into three or four main regional groups which differ in vegetation, stratigraphy, and climatic conditions. Fig. 1 shows the general geographic distribution of these major groups of peat land.

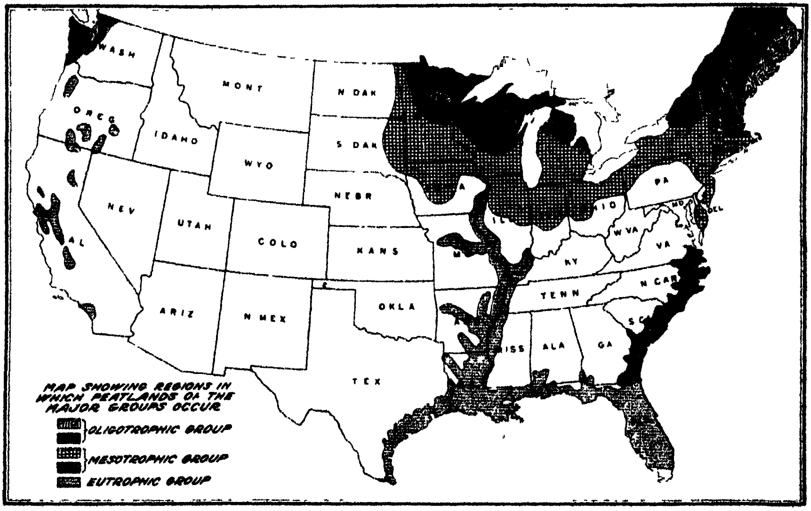

FIG. 1.—Map showing the geographical distribution of major groups of peat land in the United States.

THE EUTROPHIC GROUP

The first of the major divisions, designated as the eutrophic group, consists of peat areas whose typical characteristic layers are derived from predominant marsh and grass vegetation, have an abundance of mineral matter, are neutral to alkaline in reaction, and appear to be limited to areas with land forms subject to periodic flooding. Among the outstanding members in this division are the Florida peat lands, including the Everglades. The areas are characterized by the presence of saw-grass (Cladium) peat and layers of sedimentary peat. Lime is found in some quantity throughout the entire profile but is more highly concentrated in the layers where bands of shells or of Chara marl and algal incrustations occur. California and Oregon have peat deposits belonging to this major group. They are found at both low and high altitudes, Within this region are large areas of peat which consist almost entirely of tule (Scirpus) and reed (Phragmites) and show a tendency to accumulate salts of the alkalies or alkaline earths near the surface. An intermediate section of eutrophic peat lands is found along the mouth of the Mississippi River, extending a considerable distance inland from Louisiana and Tennessee to the prairie states. They are broken by areas covered with deciduous shrubs and forest trees which invade dry portions of the marshes.

The peat soils of this major division vary in color from brown to black in the sub-tropical belt of Florida to gray-brown and grayish-black in the delta region of semi-arid California and the inland valleys of the Klamath and Willamette in Oregon. Below the water table, the layers of peat are lighter in color and more coarsely fibrous in texture. The material is easily plowed and shows a marked tendency to granulation with small clod-like fragments. The smooth level plains are ideal for machine culture. As a group, the peat soils are relatively unleached and adequately supplied with nitrogenous substances, but their productive capacity may be limited by excessive and hence injurious accumulations of lime and other salts to form an alkaloid complex. Agriculture must be practiced with the assistance of irrigation water, since the average rainfall is not sufficient to maintain cultivated crops or forage for livestock.

THE OLIGOTROPHIC GROUP

In contrast to the belt of marsh peat lands, tending in a southeast-northwest direction, is the second main division or oligotrophic group which comprises areas containing moss peat over sedge peat, or woody layers derived from heath shrubs and conifer forests. The more important members include poorly drained land forms whose water table has been rising and stands at the surface or near it for a large part of the year. They may be found from the northern Atlantic Coast to the northern portion of the Great Lakes states, in the Alpine zone of the mountain ranges, in the Puget Sound trough, and along the northern Pacific Coast. It is interesting to note that spruce, fir, and birch, and to a lesser extent tamarack, as well as cedar, are the characteristic tree-cover of the eastern and western boreal conifer forest, at high altitudes in the mountains and at low levels. This great region is broken by many interspersed areas of heath and sedge moors, and it includes at two independent points, in Maine and Minnesota, a belt of "highmoors". The dome-shaped, raised moors on the northeastern coast of Maine and the less extensive areas of moss peat west of Duluth, Minnesota, appear to indicate a moist-cold climatic relationship, probably a similarity of such values as high rain-factor and low saturation deficiency of air.

The peat materials at the surface consist usually of Sphagnum moss peat, varying in thickness from less than 1 foot to more than 10 feet in the raised moors of Maine. The underlying layers are woody peat which are often found superimposed upon layers of sedge and reed peat. The parent peat layers are brown to reddish- and yellowish-brown in color, strongly acid in reaction, and deficient in available nitrogen and mineral salts, notably lime.

The members of this division are subject to the same processes which lead to the formation of the podsolic group of mineral soils. A large portion of these peat areas forms at present lands of marginal economic production. The acid condition calls for application of lime. Stable manure as well as complete fertilizers must also be applied. When cleared and drained they will not endure continuous cropping unless careful attention is given to the control of the water level and to nitrogen starvation. Frosts as well as a short growing season are a further limitation to their agricultural value. Commercial crops are confined to limited production of hay and specialties like potatoes or dairy products.

THE MESOTROPHIC GROUP

A third main division, designated as the mesotrophic group, embodies the transitional areas of peat which exhibit a more or less complex stratigraphic character, showing alternations of fibrous, woody, and sedimentary layers of peat. The group includes the mixed conifer-hardwood swamps in the middle latitudes of eastern United States and unevenly distributed areas of sedge- and heath-moors under conditions of essentially incomplete drainage. Members of this group are found in ancient glacial lake beds, flat and hilly country, terraces, and lowland bordering rivers and lakes. Moderately long summers and favorable rainfall favor decomposition to a relatively greater depth and release soluble plant food constituents. Consequently, these peat soils are not as thoroughly leached and acid in reaction as the podsolic soils and oligotrophic deposits of peat of the northern region. Under a mixed conifer and deciduous forest cover (tamarack-cedar, maple-ash) the peat materials at the surface are dark in color from the accumulation of partly oxidized fibrous and woody debris, and they have a significant though low content of available nitrogen. Occasionally lime and phosphates are present when decomposition is in a fairly advanced stage. Cleared and moderately drained they react quickly to manure and fertilizers. But as soon as the content of decayed organic matter is low at the surface, the areas become less fertile and will not respond to cropping without careful management of the underlying layers of coarser and rawer peat material and the addition of nitrogen and mineral fertilizers.

The principal crops are grains like corn, hay, and various specialties. The growing period is frequently interrupted by a dry or a cool season and hence grain and live stock farming are a much safer type of peat land agriculture than any intensive cropping with specialties, such as onion, celery, or peppermint.

UNCLASSIFIED GROUP

Besides these main regional divisions there is one other group which does not fit into any of the three larger units, being a remnant of peat-forming vegetation that is now more or less restricted and localized. The Dismal Swamp in Virginia and the Okefinokee Swamp in Georgia are among the noteworthy and largest examples in the belt of peat areas which border the Atlantic Coast. The deposits are characterized by the presence of plant remains from cypress, white cedar, red gum, tupelo, and white and red bays. They occupy terraces, streams, and sloughs that remain under water during most of the growing season or are subject to overflow for several months.

The peat soils of this major group have not been studied extensively enough to permit a definite assignment to a separate group. In several respects they are comparable to the mesotrophic group of peat lands. They are predominantly woody but acid in reaction, and as a whole not highly productive in their present condition. Their cultivation has in many cases been accompanied by an early decrease in crop yields. This restricted fertility is an economic drawback of considerable significance.

In the preceding discussion only generalized descriptions, characterizing each main group, have been given. As a basis for further advancement in our knowledge of American regional peat lands, the deposits in Alaska, Canada, Mexico, and South America should be studied with as little delay as possible.

ANALYSIS OF PEAT PROFILES

A very important part of the program in which the Peat Subcommission is destined to play a rôle concerns analytical data of peat profiles. It is essential that specific information be provided on the characteristic physical and chemical properties of the layers in regional peat profiles and of the transition stages which result from the influence of drainage, cropping, and other factors. It will be impossible to take any practical advantage of scientific peat investigations or to apply the experience acquired in one state or country to the improvement of practice in another place, unless a clear conception can be obtained, by means of uniform working methods, of the important physical and chemical properties which determine the reaction and behaviour of peat lands in different regions.[3]

Very little work has been done in studying or considering the physical properties of different types of peat profiles. These studies can be carried on simultaneously with some of the other problems mentioned below. The technic of the physical and mechanical tests is now the subject of special study with members of the First Commission of the International Society of Soil Science.

Researches are being continued also upon methods to be used for the chemical analysis of the individual layers which constitute peat profiles. Information upon well-identified profiles is all too meager and greatly needed from different parts of the world. It seems useless to attempt elaborate studies of chemical complexes or of the process involved in decomposition before we have a clear understanding of the botanical composition of the various layers which regional areas of peat actually contain.

The simplest methods of chemical analysis reported are similar to those used for crops and feeding stuffs. The results published in an earlier paper (JOUR. AGR. RES., 29: 69-83, 1924) are fairly accurate as to the determination of regional differences in the chemical composition of organic constituents of peat and muck. These show, for example, that no differences exist in the chemical composition of sedge peats from the Great Lakes states, e.g., from Michigan and Minnesota. In the southern region, however, a tule peat from California contains a higher content of ether-alcohol soluble constituents and a considerably lower content of protein and crude fiber complexes than saw-grass peat from Florida.

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[3] For a classification and properties of some of the more important types of peat see U. S. D. A. Bul. 802, 1919. The rôle of microorganisms was reported in Bul. 16 of the Geological Survey of Ohio, 1912. Photographs of peat materials and cross sections illustrating different series of peat profiles are shown in U. S. D. A. Bul. 1419, 1926. The cross sections of Plate 1 represent various successions of peat layers and characterize series of limnogenic, telmatogenic, and terrestrogenic profiles.

It is interesting to compare these results with the chemical composition of sedimentary peat from Lake Okeechobee, Florida; from Fremont, Indiana; and from Middle River, California. This study again brings out the fact that a notable increase in the ether-alcohol soluble fraction and a corresponding decrease in protein content characterizes the peat materials from the semi-arid West. Differences in fiber content are not marked, however.

Analyses of the composition of organic constituents of three Sphagnum moss peats from Maine, Minnesota, and Alaska tend further to confirm the significance of botanical composition and correlated differences in chemical complexes between peat materials. The increase in the quantity of waxy, resinous constituents of the peat from Calais, Maine, is especially illuminating, since it depends upon the fact that a greater variety of ericaceous plants preponderates on the highmoors of the northeastern coast of Maine. The Sphagnum moss peats are otherwise very similar to one another and noteworthy for their low ash content, low nitrogen content, hihg acid reaction, and relatively high content of fibrous substances, such as lignins and celluloses

When a comparison is made of the chemical analyses of woody peats from the Great Lakes states, we can readily recognize differences that correspond to derivation from forests of deciduous trees or conifers A typical analysis of the chemical composition of a woody peat from Indiana, when compared with samples of woody material from Michigan and Minnesota, definitely established the fact that peats originating from boreal conifer forests (spruce-fir-birch) contain a higher content of ether-alcohol soluble constituents and a lower content of protein than peats derived from mixed deciduous forests (tamarack, maple-ash). The woody peat from Indiana shows not only a smaller fraction of waxy and resinous components, but also a larger quantity of nitrogenous substances. The marked reduction in the fiber content indicates that decomposition, produced by drainage and aeration, is accompanied by decrease in crude fiber complexes and followed by an accumulation of nitrogen in an available form. The analyses reported for reed peat and reed muck from Ohio illustrate, it seems, a similar process of decomposition, the destruction of the less resistant constituents in the fiber complex, and an increase in nitrogen derived from various sources. The more resistant fiber residue and wax-like constituents contribute to the formation of reed muck. The results obtained point to distinct differences in the chemical nature of regional areas of peat and bring out the fact that the nature and chemical composition of muck from different peats are not the same.

The chemical composition of several types of peat in this country and the nature of the process involved in decomposition have been determined recently in much detail by Dr. S. A. Waksman of New Jersey. Forthcoming reports from Dr. H. G. Byers of the U. S. Bureau of Chemistry and Soils, dealing with further investigations of the chemical complexes in peat materials of different kinds, and from Dr. Waksman relative to bacteriological studies of various peat deposits will be welcomed by those interested in selected methods for the examination and analysis of peat profiles. It is hoped that other investigators will accentuate certain inorganic chemical studies of peat and muck.

Several problems have been submitted and the questions thus raised might constitute the basis of a plan of procedure for international cooperation. Dr. J. E. Hissink of Holland has proposed a method for determining the exchangeable bases and the degree of saturation, i.e , the potential absorption capacity of peats and their decomposition products for certain chemicals, while Dr. W. L. Powers of Oregon is preparing a report dealing with the preparation of peat soil extracts and the chemical study of the changes in the character of ground waters and saline contaminations of regional peat lands.

ECOLOGY OF PEAT REGIONS

Another important duty or function of the Peat Sub-commission is that which concerns the aspect and composition of the principal peat-forming vegetation units, especially with regard to the present and past successional relationships and geographic distribution. Increasing knowledge demonstrates more and more clearly that the structural features of peat profiles offer important testimony upon the history of their respective regions. The application of the methods of ecology to the past has led to the point of view that areas of peat serve as a key to unlock the past in terms of successional stages of vegetation, leading to the permanent or climax vegetation which continues as long as the fundamental climatic conditions do not change materially.

Regional areas of peat, and their more or less definitely developed chief layers of peat, are, therefore, records of the first importance, since they bear witness beyond question to changes in plant and animal migrations, in environmental conditions, and to the general relation between plant succession, climax vegetation, and climate from the present to the past. Nearly a decade ago and again last year the writer endeavored to trace, in peat deposits of Europe and America, the periodicity of climate since the last glaciation (reports of the conferences on cycles, Carnegie Institution of Washington, pages 55–64, 1929). The developmental processes in vegetation and the basic dependence of the great groups of natural vegetation upon climate have supplied the guiding principle for botanical peat investigations. They contain also the promise of a better selection and utilization of peat lands for different practical purposes.

The study of the ecological relations for regional peat deposits in different parts of the world has been undertaken by the branch committee on ecology headed by Dr. F. E. Clements of the Carnegie Institution of Washington. A report will be presented by Dr. Clements before the Sub-commission as a basis for the application of uniform ecological methods, concepts, and vegetation units to the peat areas of the world. More rapid and consistent progress may be anticipated in determining the botanical complexity of peat profiles, reconstructing the vegetation of the different periods, and inferring from these the approximate climates under which they flourished.

PRACTICAL PROBLEMS

We may now turn to that group of practical problems which relate to the improvement of peat lands by means of drainage, by admixture of chemical fertilizers, by the kinds of crops to be grown, and where and how to grow them. It is obvious that for the selection of areas of peat suitable for sound economic development, for the protection of peat lands and crops from destructive agencies, and for the effective conversion of raw types of peat into commercial commodities, we must have specific and accurate information regarding the structure and reaction of peat lands and fill any gaps in our knowledge of regional differences between areas of peat.

WATER RELATIONS

The usual difficulty encountered in practice arises from the lack of a well-balanced water supply throughout a crop season. The specific water requirements of different crops, including forage and timber, are not the same, and the layers of a peat profile are unlike in several properties, in composition, in capacity for drainage, and in the rate and duration of supplying the needs of crops. Both the surface peat soil and the layers below react to drainage by changes which are far too complicated to be expressed by a mathematical formula. Obviously, no satisfactory interpretation of observed phenomena can be made, and no appropriate supplementary or general remedy can possibly be planned, unless we attempt to correlate the effects of drainage with the structural conditions existing within an area of peat. We need to know with greater accuracy the time required for different structural combinations of peat profiles to adjust themselves to conditions of drainage, the nature of these readjustments, and, as a consequence, the time required for the movement and removal of water or the movement of salts and gases under normal and extreme field conditions.

The problem of regulating the water supply offers an outstanding international opportunity for securing a systematic collection of empirical facts concerning the results and the range of the effects of artificial changes produced by open ditches and tile. The service which areas of peat may render as natural water storage basins in ameliorating floods and erosion, in regulating the flow of streams, in constituting a protection to wild life, and against frost and fire hazards should not be neglected. A well-planned, carefully executed scheme of water control, including both drainage and irrigation, would go further than any other means toward checking the effects of drought periods, wind erosion, frost damage, and the great destruction of drained peat land by reckless fires.

Measures for the control of drainage would contribute reliable data also on the relationship between water supply and the production of food and forest crops to which peat lands are amenable. In order to shed some light on the damage by frost and fire and in order to overcome these difficulties, accurate records should be kept, including the differences in the injury rate through these agencies.

The importance of the drainage problem is very great indeed, and the Peat Sub-commission can justly congratulate itself on having Professor S H McCrory with members of the Sixth Commission as a branch committee on methods of peat land drainage

BIOCHEMICAL REACTIONS

Another line of work deserving serious attention in more than one state and country has to do with the control of biochemical reactions of peat areas. From such control have resulted the successful operations in peat land agriculture. It is expected to determine not only the amount and nature of muck and humus produced periodically by cultivation, but also to provide some estimate of the amount lost by oxidation, fires, and wind erosion, and, in consequence, the length of time required for an area of peat to disappear when under cultivation.

FERTILIZERS

New methods of fertilizing have been brought forward recently[4] and now conclusions have been arrived at which are of fundamental importance and capable of wide application. Increasing attention has been paid of late to manganese, copper, sulfur, iodine, and other chemicals in promoting the growth and yield of crops; but opinions have been at considerable variance as to the actual effect, for example, of manganese sulfate on peat lands with a relatively high lime content.

A great drawback to the work is the fact that the experiments hitherto made are not comparable because of the employment of differing types of peat land and of widely differing methods of investigation. There is also the problem of alkali spots on areas in semi-arid regions, the nature of the injury caused by an excess of soluble salts, and the question of the adequacy of concentrated and complete forms of commercial fertilizers applied to peat lands, regardless of the character and composition of the parent peat layers or the presence of certain mineral salts accumulating in regional peat profiles. In the present state of peat investigations the attempts of Dr. R. V. Allison of Florida to examine the response of plants and peat soils to unusual chemicals and, by suitable modification, to produce methods and field practices for adoption in other states, can not fail to be of great service in advancing the subject of special and rare mineral salts and the function of these chemicals under different field conditions.

EXCHANGE OF SEEDS AND PLANTS

As opportunity offers, the Peat Sub-commission will facilitate the exchange of selected seeds and plants among the member countries of the International Society of Soil Science, and will also encourage cooperation in the introduction, breeding, and propagation of improved and new varieties of seeds and plants.

There is also the practical detail of collecting data pertaining to crops, insect pests, and plant diseases, and of developing cropping systems suitable to the special conditions on peat lands of each country.

LEGITIMATE USES OF PEAT

A word should be said also about the Peat Sub-commission's endeavor to aid in increasing the production and legitimate use of certain types of peat material for stable bedding, poultry litter, packing fruits, bulbs, and vegetables, and composting organic waste products with peat wherever manures are desired. The value of moss peat imported for consumption in this country represents $500,000 annually. Chemical and microbiological investigations underlying the decomposition of peats and their uses in an efficient system of improving mineral soils are becoming more and more pressing.

CONCLUSION

The object of this paper has been to call attention to the main lines of work that are under consideration or await further study, rather than to present results. Peat investigations require organization, a central station, and prolonged research. It is greatly to be hoped that the national sections will each maintain an information service or clearing house for projects, staff members, publications of their scientific institutions, and for the methods and results of agricultural work on peat lands of different types.

The study of regional areas of "Low Moor" (Niedermoor) has been proposed from the point of view of stratigraphy, profile analyses, and cultural operations on a comparative basis, with the view to adopting a uniform procedure in peat investigations. In this connection, Dr. Hissink suggests consideration of a nomenclature in three languages, German, French, and English. By adopting more uniform methods, terms, and criteria, the investigations, under way and proposed, will not only increase our knowledge concerning deposits of peat and the conditions affecting them, but will also hasten the solution of those peat problems that have application and value for all countries.

THE CENSUS AS AN AID IN MAPPING SOILS DEFICIENT IN PHOSPHORUS[1]

C. A. MOOERS[2]

Scientific investigation of the soil has often been directed by the practical experience of the farmer. Established farm practice is usually well founded, even when there is room for improvement. The usage of fertilizer is no exception to the rule and furnishes valuable information in regard to soil requirements. The United States Census of 1920 reports the fertilizer used, by counties, and includes both the expenditure and the number of farms which use it. This information, together with the area of the county, furnishes the data for calculating on a uniform basis the comparative usage of fertilizers in all parts of a state.

Corn, as a representative farm crop, removes fertilizer constituents, roughly, in the proportion of 1 part of phosphoric acid to 3 of nitrogen and 2 of potash. A fair representation of the so-called complete fertilizer used in 1919—the year the census was taken—carried 9% of available phosphoric acid, 2.5% of nitrogen, and 3% of potash. The preponderance of phosphoric acid in the fertilizer is greatly accentuated by comparison with the ratios removed by crops. These and other considerations, such as the light application commonly made and the narrow margin of profit from the high-priced ammoniates, which along with potash salts are little used alone, admit of the assumption that the use of fertilizers in the past has been principally limited to soils deficient in phosphorus. If so, either the money spent for commercial fertilizers per acre of improved land, or the percentage of farms using fertilizer regardless of composition—whether plain superphosphate, a phosphate and potash mixture, or a so-called complete fertilizer—serves primarily as an index of the soil supply of available phosphorus. The phosphorus supplies of Tennessee soils have been studied by the Tennessee Agricultural Experiment Station for many years, and a comparison between the experimental findings and farm practice should therefore afford important evidence on the subject.

Fig. 1 is a map of Tennessee showing the comparative use of fertilizers on the basis of the expenditure per acre of improved land.

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[1] Contribution from the Department of Agronomy, Tennessee Agricultural Experiment Station, Knoxville, Tenn. Presented as part of the symposium on "Phosphorus" at the annual meeting of the Society held in Chicago, Illinois, November 14, 1929.

[2] Director.

Fig. 2 shows the same thing, but on the basis of the percentage of farmers using fertilizer. The general appearance of the two figures is much the same, but a detailed study discloses material differences. For example, in Fig. 1, the use of fertilizers in Shelby County is indicated as more extensive than in Sevier County, and this is true on the basis of expenditure. On the other hand, in Fig. 2, a decidedly opposite condition is shown because only 2.5% of the farmers in Shelby County used fertilizer as compared with 25% in Sevier County. For the present purpose, therefore, the percentage basis is taken as the better index because it is a more definite expression of widespread soil condition. However, on either basis there are disclosed two large areas, one in middle and one in west Tennessee, where fertilizers were little used.

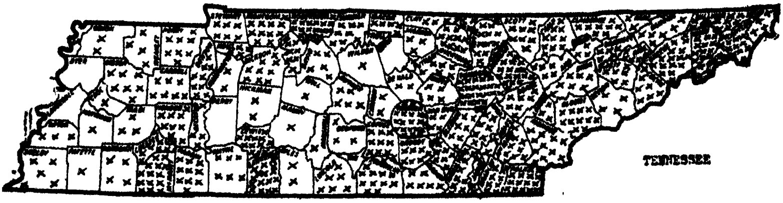

Fig. 1.—The comparative use of fertilizers on the basis of the expenditure per acre of improved land.

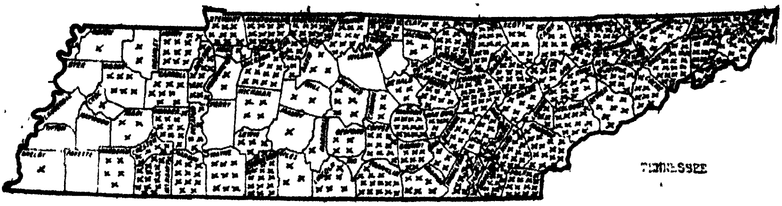

Fig. 2.—The comparative use of fertilizers on the basis of the percentage of farmers using fertilizer.

Field and laboratory studies have shown conclusively that the soils of the major portion of the central basin of middle Tennessee are rich in phosphorus, but that the soils of the highland rim surrounding the basin are poor in this element. Accordingly, the boundaries of the basin were drawn as shown in Fig. 3, and the fertilizers in the border counties were alloted chiefly to the rim section. In the case of Rutherford County, which lies entirely within the basin, and in a portion of Bedford County, the Experiment Station has found that the so-called red lands of these counties are moderately deficient in phosphorus. This is in harmony with the census data as indicated.

A few years ago the soils of west Tennessee had not been studied as thoroughly as those of other large divisions of the state, and the data from field experiments and chemical analyses were insufficient to allow of a satisfactory mapping of the phosphorus requirements of this section. In this instance the information afforded by the census was of great assistance.

The abrupt falling off in the use of fertilizers from the eastern to the western border of this section, together with the knowledge that the soil supplies of the mineral elements were generally in harmony with the geologic formations in the state, led to the demarcation of two major zones, the eastern and the western, as shown in Fig. 3. The western zone is covered by the loess and LaGrange formations. The line of demarcation between the zones follows the junction between the LaGrange and the Porter's Creek group, but may have to be modified as the result of future investigation. The West Tennessee Experiment Station is located at Jackson, which is in the western zone not far from the border between the two zones. At this station, although the soil contains less than 0.06% of phosphoric acid soluble in strong hydrochloric acid by the old official method of soil analysis, little response to phosphatic fertilizers has appeared even after 20 years of continuous crop removal. At the end of that period cowpeas and other crops grew practically as well without as with phosphates. On the other hand, on a farm near Paris, located only a short distance across the border in the eastern zone, the response to phosphates was marked. Additional data from field experiments conducted at other points in west Tennessee are in harmony with the present mapping, which has been satisfactorily used for the past two years as a guide in improving the fertilizer practice of this part of the state.

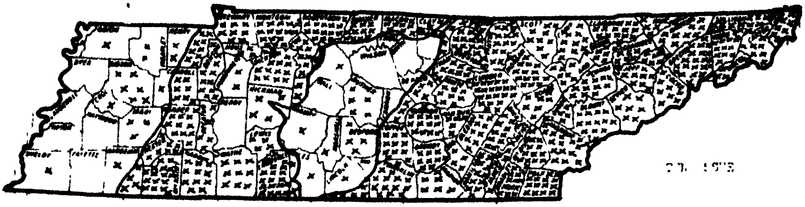

FIG. 3.—The comparative use of fertilizers on the basis of the percentage of farmers using fertilizer, but modified with regard to geologic horizons in middle and west Tennessee.

Although the conclusion is reached that farm practice in the use of commercial fertilizers as shown by the census of 1920 may be used as a supplemental guide in the mapping of phosphorus-deficient areas, some possibilities must always be kept in mind. For example, there is a group of three counties, *viz.*, Perry, Humphreys, and Hickman, where very little fertilizer is used, but their location is on the highland rim which is supposed to be poor in phosphorus. In these counties most of the farming is done on fertile bottom lands, and this fact together with isolation and poor roads may explain the situation. The kind of crops extensively grown influences the amount of fertilizer used. Relatively high priced crops, such as tobacco, cotton, and truck, are more liberally fertilized than a crop of low acre value such as wheat, but the percentage basis overcomes this factor to a great extent. The possible great need of nitrogen and potash must also be taken into consideration, and this condition appears to explain the wide use of fertilizers in Gibson and adjoining counties where truck crops are extensively grown. In this case a reduction in phosphoric acid and an increase in the amount of fertilizer nitrogen was recommended and proved highly profitable in practice.

THE ROLE OF SULFUR IN PLANT NUTRITION[1]

W. L. POWERS[2]

Striking increases in the yield of alfalfa have been obtained by the Oregon Experiment Station in sulfur fertilizer trials dating since 1912. The writer has been associated with these sulfur studies from their inception, and has given much study to the question of the ultimate effect of sulfur treatment upon the soil and to the rôle played by sulfur in plant nutrition. In a study of sulfur as related to soil solution, three effects of sulfur treatment were found to stand out, namely, (a) a more favorable concentration of sulfate in the soil solution of certain soils during the early growth period; (b) a marked increase in the amount of calcium and other bases brought into solution in the moist soil; and (c) an improvement in the reaction of arid and semi-arid soils to plant nutrition

The concentration favorable for optimum growth of alfalfa seedlings under the conditions studied was found to be 15 to 30 p p.m. during the first three weeks and 8 to 15 p.p.m during the next three weeks of the growth period Early in the growing season the concentration of sulfate in the soil solution of some soils was found to be lower than this optimum Soils with a sulfate concentration as low as 13 to 17 p.p.m. were found, and diffusion would probably be slower in the soil than in the water culture in which the concentration experiments were conducted.

A survey of sulfur trials and examination of soils used indicates that soils of the northwestern states that respond best to sulfur are the residual, calcareous, basaltic lands, especially where there is good natural drainage and the precipitation or irrigation water is relatively pure. These soils are naturally relatively low in sulfur content In numerous cases the soils that respond to sulfur treatment are found to yield a relatively large amount of exchange calcium.

The soil reaction which is found to be most favorable for the growth of young alfalfa is one that is faintly acid. Alfalfa is found to grow best at a reaction value of about 5.6 to 6.0, where a reaction value of 7 represents neutrality and a lower value indicates a condition more acid than pure water. In this faintly acid medium iron and phosphate may usually be expected to come into solution in the soil water to a more favorable extent, and phosphates, sulfates, and nitrates are known to be taken into the plant in greater quantity. A little sulfur added to soil of slightly alkaline reaction may aid activity of micro-organisms connected with nitrification, while sulfur in larger amounts or on acid soils may tend to inhibit their activity. Concerning the effects of sulfur on micro-organic activities, however, further study is needed. Sulfur has proved the most effective single treatment for correcting "black alkali", where deep drainage and irrigation are employed, as at Vale Experiment Field (1).[3] Less sulfur is needed for improving black alkali land if used in conjunction with bulky nitrogenous organic matter.

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[1] Contribution from the Soils Department, Oregon Agricultural Experiment Station, Corvallis, Oregon. Presented, with approval of the Director, at the annual meeting of the Society held in Chicago, Illinois, November 15, 1929.

[2] Chief in Soils.

Changing the reaction of arid soils from faint alkalinity to faint acidity by sulfur additions results in an increase in concentration of bases, in the soil solution, such as potassium, calcium, and magnesium. Legumes, such as alfalfa, require about 200 pounds of calcium in a 5-ton crop. Usually there is an increase in concentration of calcium in the soil solution following the application of sulfur. With certain soils, such as the Deschutes sandy loam, the increase in the soluble potash is more important The increased drought resistance of alfalfa grown where sulfur has been applied is probably due in part to a better floculated condition of the soil resulting from an increase in water-soluble calcium.

Another function of sulfur seems to be that of aiding the formation of chlorophyl Potatoes dusted with landplaster, or grown on alfalfa sod land which has been sulfured, or treated with ammonium sulfate develop a darker green color. A similar effect has been noted where sulfur or landplaster has been used with corn or tomatoes. The writer has found an increase of 12% in the chlorophyl from sulfured alfalfa plants and 18% increase in the chlorophyl in the leaves of alfalfa grown on land that had been treated with sulfur. Ellis (8) seems to have established a relation between the S-H bond and infra-red absorption. Sulfur increases stem strength and leaf thickness and lessens shattering of alfalfa leaves in haying.

Miller (2) has shown that sulfur increases the protein content of alfalfa. It is known that sulfur is a constituent of the protein cystine. Sherman and Woods (6) report experiments with rats that seem to prove cystine may be a nutritionally essential amino acid and the limiting factor in growth. Addition of cystine to a low-casein diet induced a normal rate of growth which was immediately checked when the cystine was withdrawn and resumed when cystine was again added to the diet. Small additions of cystine were found to give quantitatively proportional increases in gain until a point was reached where this substance is no longer the limiting factor.

Lewis (7) reported that a lower condition of protein intake maintained weight of dogs, if high cystine protein was uesd. Long-haired dogs are reported to require the larger amount of cystine in the maintenance ration. With rats a low cystine ration causes short hair, while high cystine induces the long hair to appear earlier on young rats, or to induce longer growth of hair, according to Dr. Woods. In view of the known high cystine content of hair and the increase in protein of alfalfa resulting from use of sulfur as a fertilizer, it is suggested that alfalfa so fertilized may prove more useful for feeding sheep for yield or quality of wool.

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[3] Reference by number is to "Literature Cited," p. 373.

A small amount of sulfate has been reported (5) to stimulate yeast growth. Yeast is able to utilize sulfate and presumably convert it into protein sulfur. There is a possibility that animals cannot assimilate sulfur directly, but that they require feeding by plants that can use this mineral.

Recent investigations by Warburg (3) suggest that the sulfhydryl (SH) group accelerates formation of plant fat and aids in oxidation of protein. More recently Hammett (4) has reported experiments which strongly indicate that this SH group makes possible growth in plants and animals by division of cells and that the group may be fairly called the key compound to life itself by being "the essential stimulus to growth by increase in cell number."

The evidence in support of this conclusion is based on the value of lead compounds for checking the rapid cell division that occurs in cancer, and is similar to the stimulative responses in trials with growing plants. Hammett grew plants in solutions of lead compounds and found that the cells enlarged but did not divide much. The SH group was found abundant in the region of rapid-growing roots. Compounds containing this group extracted from actively growing roots when applied to the tips of other growing roots caused accelerated growth. Synthetic SH-containing compounds produced like effect, both on growing root tips and on single-celled water animalcules. This pair of atoms which attaches to many chemical compounds is probably "the life of the party," in that it catalyzes or accelerates vital life process of cell division.

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CROP RETURNS FROM THE USE OF FERTILIZER[1]

H. R. SMALLEY[2]

Haskell[3] has estimated that in 1923 the crop returns from the use of commercial fertilizer were approximately $697,000,000. According to the United States Census of Agriculture for 1925, farmers spent approximately $230,000,000 for fertilizer in 1924. It may be assumed that about the same amount was spent in 1923 and that roughly, according to Haskell's estimates, farmers obtained about $3 increase in added crop value for each dollar expended for fertilizer. So far as the writer knows, this is the only estimate that has been made of total returns from the use of commercial fertilizer.

During the spring and summer of 1928 a survey was made by The National Fertilizer Association, through the cooperation of about 60 member companies and some 900 salesmen, which involved personal interviews with 48,000 farmers located in 800 different counties and in 35 states. One of the 26 questions asked was, "From your general experience what increases do you expect from the use of fertilizers on your most important crops?" In answering this question each farmer gave his average yield with fertilizer and the average yield that he would expect without fertilizer.

The figures and conclusions here given are based on the farmers' estimates of the increase in yield obtained by the use of fertilizer, the percentages of acreages fertilized, and the approximate quantities used on certain crops, as reported in *American Fertilizer Practices;*[4] the value of crops, as reported by the U. S. Department of Agriculture in *Crops and Markets;* an estimate of the average price paid by farmers for fertilizer used on cotton, as shown by figures published by the U. S. Department of Agriculture in *Crops and Markets;* and an estimate made by the author of the average price paid for fertilizer used on other crops.

The farmers' estimates of increased yield obtained by the use of fertilizer are the most comprehensive estimates of this kind ever obtained, and it therefore seems worth while to employ them to determine approximately the returns that farmers obtain by the

[1] Presented at the annual meeting of the Society held in Chicago, Illinois, November 15, 1929.

[2] Director of Soil Improvement Work, The National Fertilizer Association, Washington, D. C.

[3] HASKELL, S. B. The economics of fertilizer use in the United States. Jour. Amer. Soc. Agron., 17:198. 1925.

[4] American Fertilizer Practices, published by The National Fertilizer Association, 1929.

use of fertilizer. Cotton, corn, potatoes, wheat, and tobacco consumed about 85% of the fertilizer used, and these crops are fully covered by the farmers' estimates. Provisional estimates have been made for the minor crops, but these estimates are lower than those made for the same crops by the farmers themselves.

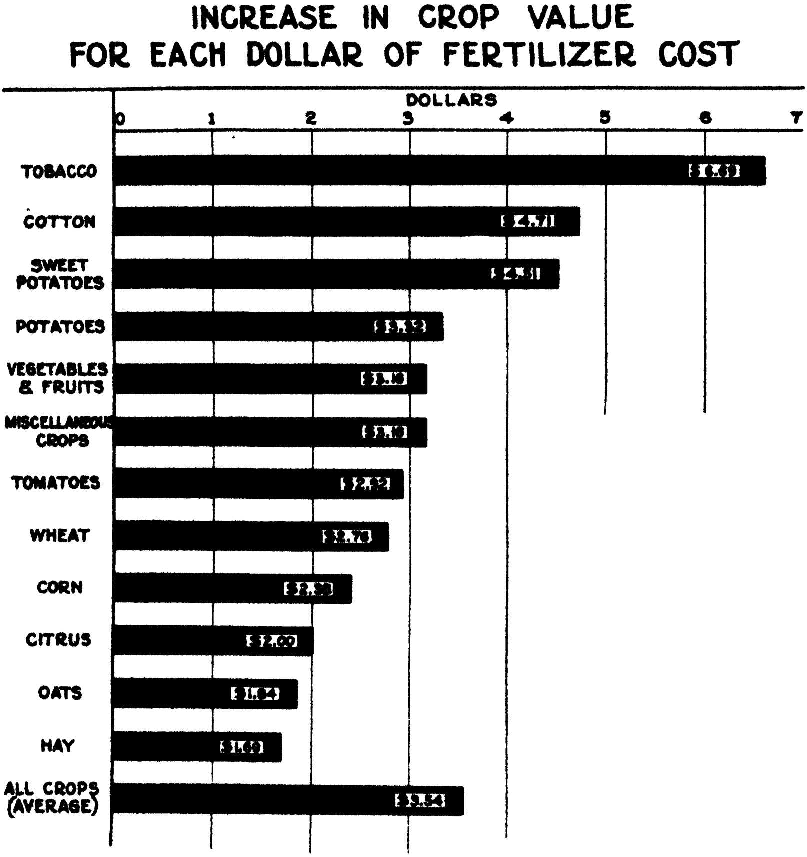

FIG. 1

The percentage of the total value of the crops produced by the use of fertilizer as shown by the farmers' estimates was determined according to the following formula: Increased yield with fertilizer (farmers' estimates) divided by the yield with fertilizer (farmers' estimates) multiplied by 100 equals the percentage of the yield obtained by the use of fertilizer. This figure multiplied by the percentage of the acreage fertilized gives the percentage of the total crop produced by the use of fertilizer. This percentage is shown in the first column of Table 1.

TABLE 1.—*Crop returns from the use of commercial fertilizer, by states.*

State	Crop	Percentage of total crop produced by fertilizer	Crop value produced by fertilizer	Tons of fertilizer used in 1927	Estimated fertilizer cost	Increase in crop value for each dollar of fertilizer cost*
Maine	Potatoes	55.2	$17,640,000	172,720	$7,341,000	$2.40
	Other crops	2.7	638,000	11,030	412,000	1.55
	Total*	33.1	18,278,000	183,750	7,753,000	2.36
New Hampshire	Potatoes	35.7	825,000	7,660	326,000	2.53
	Other crops	3.7	403,000	9,215	353,000	1.14
	Total	9.4	1,228,000	16,875	679,000	1.81
Vermont	Corn	20.0	717,000	5,980	209,000	3.43
	Potatoes	23.6	861,000	5,100	217,000	3.97
	Oats	7.8	152,000	2,030	71,000	2.14
	Hay	0.9	166,000	2,520	101,000	1.64
	Other crops	0.9	3,000	30	1,000	3.00
	Total	6.9	1,889,000	15,660	599,000	3.17
Massachusetts	Hay	10.3	1,463,000	26,920	1,077,000	1.36
	Corn	20.6	480,000	13,760	482,000	1.00
	Potatoes	43.4	1,049,000	10,830	460,000	2.28
	Tobacco	48.2	1,545,000	10,900	600,000	2.58
	Vegetables and fruits	27.7	862,000	9,320	351,000	2.46
	Total	21.4	5,399,000	71,730	2,970,000	1.82
Rhode Island	Potatoes	42.8	196,000	1,800	76,000	2.58
	Hay	12.9	185,000	4,230	169,000	1.09
	Corn	19.5	91,000	2,750	96,000	.95
	Vegetables and fruits	35.0	61,000	1,340	51,000	1.20
	Total	21.0	533,000	10,120	392,000	1.36
Connecticut	Tobacco	29.6	3,171,000	34,450	1,895,000	1.67
	Hay	4.5	504,000	10,010	320,000	1.58
	Potatoes	46.0	1,317,000	9,810	417,000	3.16
	Corn	15.8	428,000	10,730	376,000	1.14
	Total	19.7	5,420,000	65,000	3,008,000	1.80

New York	Potatoes	42.5	14,626,000	97,500	3,510,000	4.18
	Corn	13.2	2,802,000	49,140	1,622,000	1.73
	Oats	17.9	3,265,000	56,680	1,870,000	1.74
	Wheat	29.1	2,013,000	23,400	722,000	2.61
	Other crops	2.2	2,081,000	33,280	1,089,000	1.91
	Total	14.3	24,787,000	260,000	8,863,000	2.80
New Jersey	Potatoes	69.7	6,016,000	37,960	1,367,000	4.40
	Corn	27.8	1,831,000	24,930	823,000	2.22
	Tomatoes	39.5	2,063,000	16,570	630,000	3.27
	Sweet potatoes	59.7	1,559,000	8,220	288,000	5.41
	Hay	4.9	384,000	7,360	236,000	1.63
	Wheat	28.4	469,000	6,520	215,000	2.18
	Vegetables and fruits	33.4	3,176,000	37,250	1,316,000	2.41
	Other crops	17.4	148,000	2,830	93,000	1.59
	Total	36.4	15,646,000	141,640	4,968,000	3.15
Pennsylvania	Wheat	30.5	7,960,000	98,340	2,950,000	2.70
	Corn	15.4	7,021,000	73,590	2,208,000	3.18
	Oats	19.2	3,660,000	67,980	2,039,000	1.79
	Potatoes	29.6	8,896,000	55,110	1,819,000	4.89
	Other crops	3.7	2,873,000	34,980	1,105,000	2.60
	Total	15.4	30,410,000	330,000	10,121,000	3.00
Delaware	Wheat	55.4	1,348,000	16,440	493,000	2.73
	Sweet potatoes	61.5	454,000	6,270	219,000	2.07
	Corn	7.9	276,000	5,330	160,000	1.72
	Tomatoes	39.2	272,000	5,130	180,000	1.51
	Potatoes	50.0	298,000	4,720	179,000	1.66
	Other crops	27.5	227,000	3,110	100,000	2.27
	Total	51.7	2,875,000	41,000	1,331,000	2.16
Maryland	Wheat	51.7	6,604,000	78,380	2,351,000	2.81
	Potatoes	59.2	2,590,000	30,860	1,234,000	2.10
	Corn	10.3	1,691,000	26,900	807,000	2.10
	Other crops	36.5	3,610,000	28,860	1,047,000	3.78
	Total	34.3	14,495,000	165,000	5,439,000	2.66

TABLE I.—*Continued.*

State	Crop	Percentage of total crop produced by fertilizer	Crop value produced by fertilizer	Tons of fertilizer used in 1927	Estimated fertilizer cost	Increase in crop value for each dollar of fertilizer cost
Virginia	Corn	14.9	6,401,000	119,140	3,336,000	1.92
	Potatoes	42.5	7,480,000	82,420	3,297,000	2.27
	Wheat	36.3	4,730,000	70,180	1,965,000	2.41
	Tobacco	43.2	9,522,000	57,120	1,714,000	5.56
	Other crops	14.0	4,984,000	79,140	2,224,000	2.24
	Total	25.2	33,117,000	408,000	12,536,000	2.64
West Virginia	Corn	14.1	2,201,000	15,000	420,000	5.24
	Oats	15.5	536,000	11,600	325,000	1.65
	Potatoes	25.6	1,849,000	8,200	271,000	6.82
	Wheat	30.0	781,000	7,500	210,000	3.72
	Other crops	23.6	427,000	2,740	77,000	5.54
	Total	18.9	5,794,000	45,040	1,303,000	4.45
North Carolina	Cotton	54.8	49,741,000	452,170	12,887,000	3.86
	Corn	34.2	15,814,000	298,700	8,364,000	1.89
	Tobacco	61.8	61,139,000	263,560	8,170,000	7.48
	Other crops	23.7	13,952,000	156,970	4,720,000	2.96
	Total	47.7	140,646,000	1,171,400	34,141,000	4.12
South Carolina	Cotton	64.4	49,797,000	467,260	12,616,000	3.95
	Corn	38.5	7,814,000	148,250	4,003,000	1.95
	Tobacco	66.2	8,693,000	36,340	1,090,000	7.98
	Other crops	19.4	5,496,000	74,850	2,249,000	2.44
	Total	51.6	71,800,000	726,700	19,958,000	3.60
Georgia	Cotton	53.4	59,104,000	411,420	12,137,000	4.87
	Corn	25.7	10,804,000	178,250	5,348,000	2.02
	Tobacco	69.2	7,429,000	27,090	867,000	8.57
	Sweet potatoes	45.0	3,628,000	25,670	847,000	4.28
	Other crops	16.0	6,625,000	70,570	2,149,000	3.08
	Total	41.1	87,590,000	713,000	21,348,000	4.10

Florida	Citrus	39.8	19,303,000	241,260	9,650,000	2.00
	Corn	40.0	2,962,000	53,840	1,615,000	1.83
	Tomatoes	45.2	4,020,000	34,230	1,301,000	3.09
	Potatoes	49.9	3,317,000	27,540	1,102,000	3.01
	Other crops	37.8	8,900,000	60,510	2,080,000	4.28
	Total	40.5	38,502,000	417,380	15,748,000	2.44
Kentucky	Corn	5.5	3,590,000	35,140	914,000	3.93
	Hay	3.0	815,000	11,690	292,000	2.79
	Tobacco	8.6	4,011,000	7,980	239,000	16.78
	Wheat	14.3	544,000	6,720	175,000	3.11
	Potatoes	14.4	861,000	4,970	149,000	5.78
	Other crops	6.5	224,000	3,500	91,000	2.46
	Total	6.6	10,045,000	70,000	1,860,000	5.40
Tennessee	Cotton	15.2	5,635,000	37,450	1,292,000	4.36
	Corn	3.2	1,832,000	25,980	779,000	2.35
	Wheat	22.3	1,577,000	18,110	625,000	2.52
	Tobacco	20.4	3,079,000	6,860	247,000	12.54
	Other crops	6.3	2,870,000	24,070	746,000	3.85
	Total	9.3	14,993,000	112,470	3,689,000	4.06
Alabama	Cotton	50.8	58,094,000	348,460	11,151,000	5.21
	Corn	15.0	5,476,000	86,990	2,610,000	2.10
	Potatoes	65.2	2,165,000	15,770	552,000	3.92
	Sweet potatoes	60.2	3,588,000	11,000	385,000	9.32
	Other crops	4.5	494,000	6,700	215,000	2.30
	Total	40.8	69,817,000	468,920	14,913,000	4.68
Mississippi	Cotton	29.0	43,558,000	190,530	7,050,000	6.18
	Corn	7.6	2,162,000	28,220	903,000	2.39
	Total	25.6	45,720,000	218,750	7,953,000	5.75
Ohio	Wheat	30.5	10,167,000	111,320	3,117,000	3.26
	Corn	11.8	10,885,000	104,760	2,933,000	3.71
	Oats	13.2	4,145,000	61,910	1,733,000	2.39
	Potatoes	22.8	3,097,000	20,320	610,000	5.08
	Other crops	3.4	1,978,000	14,390	417,000	4.74
	Total	13.3	30,272,000	312,700	8,810,000	3.44

TABLE 1.—*Concluded.*

State	Crop	Percentage of total crop produced by fertilizer	Crop value produced by fertilizer	Tons of fertilizer used in 1927	Estimated fertilizer cost	Increase in crop value for each dollar of fertilizer cost
Indiana	Wheat	29.4	8,672,000	109,430	3,502,000	2.48
	Corn	9.0	8,705,000	95,240	3,048,000	2.86
	Other crops	4.2	2,810,000	35,830	1,126,000	2.50
	Total	10.4	20,187,000	240,500	7,676,000	2.63
Illinois	Corn	1.4	2,884,000	21,020	631,000	4.57
	Wheat	1.6	634,000	6,680	200,000	3.17
	Total	1.4	3,518,000	27,700	831,000	4.23
Michigan	Wheat	19.9	4,195,000	34,000	1,088,000	3.86
	Oats	7.3	1,907,000	27,670	885,000	2.15
	Potatoes	11.7	2,768,000	17,470	611,000	4.53
	Corn	5.8	2,236,000	13,830	443,000	5.05
	Other crops	4.2	3,587,000	24,260	768,000	4.67
	Total	7.6	14,693,000	117,230	3,795,000	3.87
Wisconsin	Corn	2.3	1,405,000	9,500	304,000	4.62
	Potatoes	5.4	1,182,000	8,800	352,000	3.36
	Other crops	0.5	220,000	3,000	100,000	2.20
	Total	2.2	2,807,000	21,300	756,000	3.71
Minnesota	Corn	1.2	1,011,000	7,930	278,000	3.64
	Potatoes	1.2	263,000	2,990	120,000	2.19
	Other crops	2.8	13,000	80	3,000	4.33
	Total	1.2	1,287,000	11,000	401,000	3.21
Iowa	Corn	0.2	553,000	5,260	184,000	3.00
	Oats	0.1	79,000	1,740	61,000	1.30
	Other crops	0.2	18,000	180	6,000	3.00
	Total	0.2	650,000	7,180	251,000	2.59
Missouri	Wheat	16.5	3,793,000	42,340	1,355,000	2.80
	Corn	0.8	1,009,000	8,400	252,000	4.00
	Oats	1.2	199,000	2,930	88,000	2.26
	Other crops	1.2	666,000	2,320	75,000	8.88
	Total	2.5	5,667,000	55,990	1,770,000	3.20

Arkansas	Cotton	8.5	9,782,000	56,010	2,072,000	4.72
	Corn	4.2	1,331,000	14,330	502,000	2.65
	Other crops	8.3	697,000	5,060	186,000	3.75
	Total	7.6	11,810,000	75,400	2,760,000	4.28
Louisiana	Cotton	14.0	8,588,000	49,590	1,934,000	4.44
	Corn	6.2	1,155,000	15,420	540,000	2.14
	Other crops	12.9	4,823,000	27,850	1,096,000	4.40
	Total	12.4	14,566,000	92,860	3,570,000	4.08
Texas	Cotton	2.0	9,121,000	70,440	2,677,000	3.41
	Corn	0.9	657,000	9,500	342,000	1.92
	Other crops	3.3	114,000	560	22,000	5.18
	Total	1.8	9,892,000	80,500	3,041,000	3.25
Total all states		16.3	754,343,000	6,694,795	213,233,000	3.54

*First and last columns are wieghted averages, middle three columns are totals.

TABLE 2. —*Crop returns from the use of commercial fertilizer by crops.**

Crop	Percentage of total crop produced by fertilizer	Value of crop produced by fertilizer	Tons of fertilizer used in 1927	Estimated cost of fertilizer	Increase in value of crop for each dollar spent for fertilizer
Cotton	24.9	$295,890,000	2,108,000	$64,553,000	$4.71
Corn	6.8	106,352,000	1,510,000	44,612,000	2.38
Potatoes	30.7	87,151,000	688,000	26,215,000	3.32
Wheat	23.3	56,671,000	682,000	20,515,000	2.76
Tobacco	43.7	104,963,000	470,000	15,697,000	6.69
Oats	6.0	18,111,000	326,000	9,833,000	1.84
Citrus	39.8	19,303,000	241,000	9,650,000	2.00
Hay	1.8	9,693,000	185,000	5,740,000	1.69
Miscellaneous crops	12.6	14,622,000	148,000	4,626,000	3.16
Vegetables and fruits	29.7	16,240,000	146,000	5,146,000	3.16
Sweet potatoes	42.3	16,871,000	112,000	3,739,000	4.51
Tomatoes	32.5	8,476,000	78,000	2,907,000	2.92
Average	16.3	$754,343,000	6,694,000	$213,233,000	$3.54

*For states included see Table 1.

The crop prices used represent averages for the three years 1926–28 (December 1), as reported by the U. S. Department of Agriculture. The increase in value produced by fertilizing any crop is thus easily obtained. For example, 2,490 farmers in North Carolina estimate that they obtained 367.2 pounds of lint cotton with fertilizer and only 155.3 pounds without fertilizer, an increase of 211.9 pounds, or 57% of the total crop of lint cotton grown on the fertilized area.

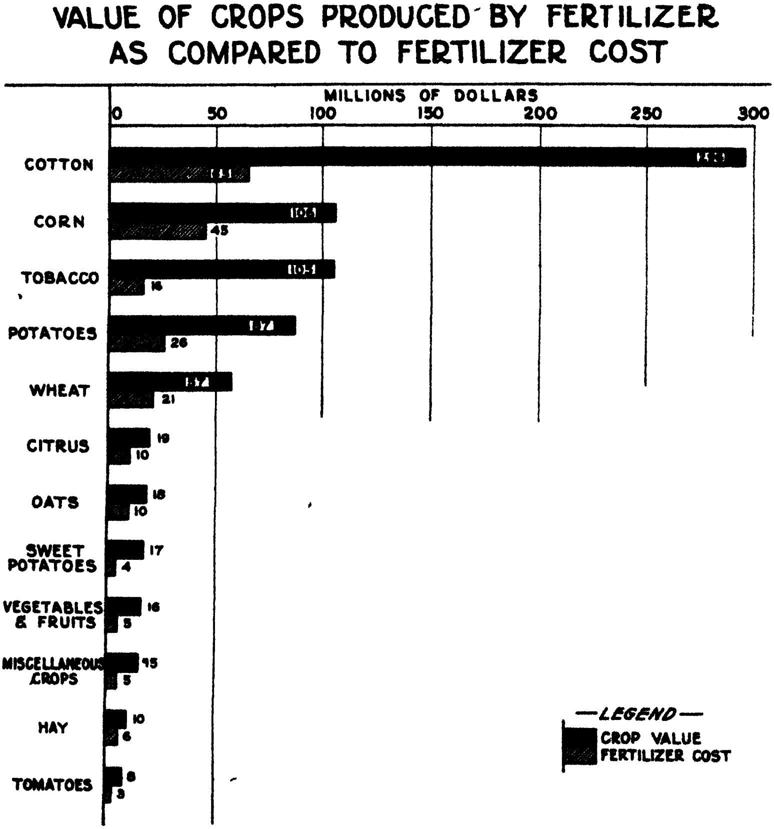

FIG. 2

The percentage of the area fertilized is 95, which, multiplied by 57.7, gives 54.8, the percentage of the crop produced by the use of fertilizer. The average farm value of the crop of lint cotton grown in North Carolina during the years 1926–28, according to the U. S. Department of Agriculture, was $77,132,000. This figure multiplied by 54.8% gives $42,268,000 as the value of the lint cotton produced by the use of fertilizer. In estimating the increase in the value of cotton, the value of the seed must be considered. The value of the seed for 1926–28 was $13,637,000, and 54.8% of this figure is $7,473,000. The total increase in the value of the cotton crop in North Carolina in 1926–28 gained by the use of fertilizer was therefore

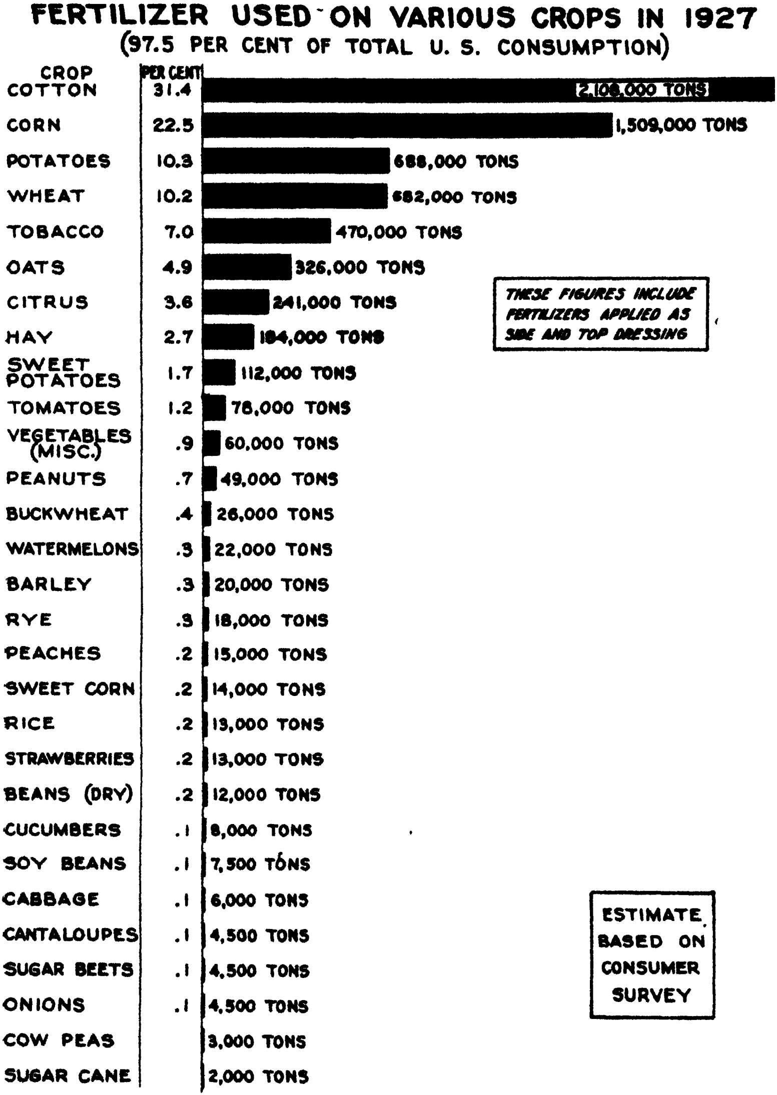

FIG. 3

$49,741,000. In estimating the increase in the value of corn, wheat, and other grain crops gained by the use of fertilizer, the value of the grain only has been considered. According to Table 1, 452,170 tons of fertilizer were used on cotton in North Carolina in 1927, and the average price paid for fertilizer by farmers, according to the U. S. Department of Agriculture, was $28.50 per ton, so that the total cost of the fertilizer used on cotton in North Carolina in 1927 was $12,887,000, and the return for each dollar spent for fertilizer was $3.86.

The percentage of the value of the crop produced by the use of fertilizer, the quantity of fertilizer used, the total approximate cost of the fertilizer, and the value of the increase in crop for each dollar expended for fertilizer are shown in Fig. 1 for the principal fertilizer-consuming crops in each of 32 states[5], which in 1927 consumed 97.5% of the total fertilizer sold in the United States. Table 2 gives a summary of these figures for the principal fertilizer-consuming crops.

The summary for the 32 states shows that the use of 6,695,000 tons of commercial fertilizer in 1927 produced crop increases worth $754,000,000, or $3.54 in crop returns for each dollar expended. At the same rate of increase the total quantity of fertilizer used in 1927 in the entire United States produced crop increases worth $771,000,000 at a cost of approximately $218,000,000. For 1928, when 7,934,000 tons were used, the value of the crop increase produced by fertilizer was approximately $895,000,000 and the cost of the 7,934,000 tons of fertilizer used was around $253,000,000. Stated in another way, a ton of average fertilizer costing $32 may be expected, under average farm conditions, to produce crop increases worth $113.

Fig. 2 shows the value of crops produced by fertilizer, as compared to fertilizer cost, and Fig. 3 the increase in crop value for each dollar of fertilizer cost.

AGRONOMIC AFFAIRS

DR. KELLEY TO STUDY NITROGEN RESEARCHES

The Executive Committee of the Society has authorized Dr. W. P. Kelley of the University of California to undertake a special investigation, under the auspices of the American Society of Agronomy, of the researches on nitrogen in relation to soils and crops that are being made in this country and abroad. This investigation will be supplementary to the work of the Chilean Nitrate of Soda Nitrogen Research Award Committee and is supported by a special fund contributed by the Chilean Nitrate of Soda Educational Bureau of New York. The object is still further to promote the primary purpose of the Annual Nitrogen Research Award by making available to the workers in this field a special report on this subject. Dr. Kelley has been granted a leave of absence from the University of California and will take up this investigation about April 15.

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[5] The returns for North Dakota, Kansas, and Oklahoma are not included since the survey was made in only one county in each of these states.

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RELATION OF ORGANIC FOOD RESERVES TO THE GROWTH OF SOME KANSAS PASTURE PLANTS[1]

A. E. ALDOUS[2]

The investigations in pasture improvement conducted in Kansas show that overgrazing and premature grazing are the chief causes for the decreasing productivity of pasture lands. The forage plants are unable to make enough top growth to elaborate sufficient food material for maintaining their vigor As a result, the more desirable plants are weakened and eventually killed. The time required for this change to take place depends upon the extent to which the pasturing abuses are practiced. Many thousands of acres of good pasture land have been made almost worthless by this practice and the productivity of much other land has been greatly decreased. As the forage plants are killed they are replaced to a certain extent by weeds, many of which have no forage value.

The restoration and maintenance of pasture lands in this region at least necessitates a knowledge of the growing requirements of the main forage species, and the application of this knowledge, as far as is practical, to the grazing management of the pasture.

The storage of organic food reserves in the forage plants is essential to their normal functioning and a determination of the extent of the storage of these reserves throughout the growing season appears to provide one of the principal indexes to the growing requirements of plants.

The work on organic food reserves of pasture plants was started only recently by the Kansas Station, so that it is possible to draw only tentative conclusions. Two economic classes of plants have been investigated. The first group included a few of the more desirable forage plants with the idea of applying data to pasturing methods to maintain or to increase productivity. The second group included the weeds from which data on organic food reserves were obtained in order to plan their eradication more effectively. This is necessary, especially, in weedy pastures, to aid in the restoration of the desirable plants.

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[1] Contribution No. 188 Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Presented at the annual meeting of the Society held in Chicago, Illinois, Novemver 15, 1929.

[2] Pasture Management.

The chemical investigation[3] with the forage plants has been done mainly with the roots of little blue stem (*Andropogon scoparius*), one of the most important grasses both in abundance and grazing value in the native prairie grass pastures, particularly in the blue stem region of Kansas. In addition, composite samples of the vegetation were taken from native prairie grass plats that had been subjected to various clipping methods of treatments. Big and little blue stems were dominant grasses in these plats. Other important grasses included indian grass (*Sorgastrum nutans*), side oats grama (*Bouteloua curtipendula*), and hairy grama (*B. hirsuta*).

The analyses of the worthless plants were confined to two common brush species that are increasing very rapidly in some Kansas pastures, *viz.*, buckbrush (*Symphoricarpos vulgaris*) and sumac (*Rhus glabra*); and two of the most abundant herbacious weedy plants, iron weed (*Vernonia baldwini*) and vervain (*Verbenia stricta*). Roots constituted the only portion of the plants taken for analysis. Samples of little blue stem and the weeds and brush were collected at two-week intervals from about May 1 to September 22. The samples from the clipping plats were all collected about the middle of October or after the plants had completed their seasonal growth. The food reserves analyzed included nitrogen, total sugars, dextrins and water-soluble starch, starch, hemicellulose, and crude fiber.

LITTLE BLUE STEM

Table 1 contains the analyses of the roots of little blue stem.

These figures show in general a decrease in food reserves during about the first month, May, but an increase during June. July shows a decrease followed by an increase again early in August, which continues until the close of the season. The decrease in the food reserves during the first part of the growing season would be expected, for it is during this time that the plant is making a very rapid growth with insufficient leaf material to elaborate food as rapidly as it is used. The data show that about June 1 the plant

[3] The chemical analysis was done under the direction of W. L. Latshaw of the Chemistry Department of the Kansas State Agricultural College.

TABLE 1.—*Percentage of organic food reserves in roots of little blue stem, season of 1928.*

Date collected	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Total starch and dextrins	Hemicellulose	Crude fiber
May 7	0.78	1.96	0.96	1.00	1.96	25.29	31.79
May 21	0.57	1.12	0.84	0.83	1.67	26.18	32.54
June 7	0.63	2.08	1.29	0.83	2.12	23.59	26.58
June 25	0.63	2.70	2.04	1.38	3.42	18.48	22.71
July 2	0.45	2.01	1.00	1.38	2.38	27.80	29.87
July 16	0.90	1.86	0.60	0.91	1.51	25.25	26.55
July 30	0.61	1.62	1.05	0.94	1.99	24.47	—
Aug. 13	0.47	2.22	1.00	1.33	2.33	26.75	26.00
Aug. 29	0.61	2.95	0.94	1.60	2.54	25.46	22.72
Sept. 10	0.48	2.70	1.41	2.49	3.90	24.48	26.76
Sept. 29	0.53	3.62	1.41	5.09	6.50	23.43	28.30

TABLE 2.—*Effect of different frequencies of cutting on the organic food reserves in grass roots.*

Plat No.	Frequency of cutting	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Total starch and dextrins	Hemicellulose	Crude fiber
		%	%	%	%	%	%	%
CV1	Every 2 weeks	0.60	3.98	2.56	4.02	6.58	23.42	23.81
CV2	Every 3 weeks	0.50	4.18	3.49	3.80	7.29	23.01	27.67
CV3	Every 4 weeks	0.69	4.54	2.31	5.20	7.51	25.98	28.89
CV5	Protected until July 1, then every 2 weeks	0.58	3.55	2.28	4.21	6.49	25.48	29.89
CV6	Protected until Aug. 1, then every 2 weeks	0.67	4.35	2.09	4.59	6.69	24.82	28.57
CV12	Every 2 weeks until Aug. 1, then protected	0.51	2.28	1.93	4.63	6.56	24.62	31.98
CV7	Check plat	0.71	4.32	2.69	7.83	10.56	22.01	26.80
H1	Every 2 weeks at 2 inches	0.55	3.77	1.02	2.46	3.49	23.61	26.98
H2	Every 2 weeks at 3 inches	1.13	4.36	0.99	4.37	5.36	22.10	26.68
H3	Every 2 weeks at 4 inches	0.65	4.84	2.21	4.94	7.15	25.26	28.24
H5	3 weeks at 3 inches	0.67	4.24	1.60	3.16	4.76	23.48	26.10
H6	4 weeks at 3 inches	0.62	4.39	1.43	4.70	6.13	25.84	26.85

is not only taking care of its requirements for food, but that it is replacing some of the depleted supply. These data indicate why grazing during the early part of the season is detrimental. They also emphasize the need for rather light grazing during the first month, or for regulation of the grazing practices so that the plants will not be too much hampered in their regular functioning during their early stages of growth. The decrease in the food reserves during July when the grass was in vigorous growing condition appears to be contrary to physiological principles and further study will be necessary before an explanation is attempted. However, if these findings are verified, the amount of decrease is large enough to receive consideration in the grazing management of pasture lands.

CLIPPING VEGETATION

The experiments in clipping vegetation were started to study the effect of various clipping treatments on native sod and were conducted so as to imitate different intensities and methods of grazing. The grass was clipped on one series of plats at two- to four-week intervals throughout the growing season and at heights ranging from 2 to 4 inches to imitate different intensities of season-long grazing, the method most generally used in pasturing livestock. Certain plats (CV5, CV6, and CV12) were protected at varying periods during the season, both at the beginning and the close, to determine the effect of these treatments which might compare with deferred and rotated grazing, on the yield, vigor, and succession of the vegetation. Table 2 contains the data.

These two series are located on two different types of pasture land. The CV series is on typical hilly, rocky, blue stem land where there are about equal amounts of big and little blue stem. The H series is established on smoother land having a predominance of little blue stem with very little big blue stem. The difference in soil and vegetation undoubtedly is responsible for the difference in organic reserves shown by the analyses for the two series.

While these figures may show some inconsistencies, it is evident that the amount of food reserves decreases with the frequency of cutting, the greatest amounts being present in the roots of plants that had not been cut or that had been cut less frequently and at the greatest heights. The effect of the more severe treatment has been very noticeable in the yield of vegetation on the plats as well as in the density of the stand. On Plat CV1, a very thrifty stand of vegetation was practically killed in two years under extremely favorable climatic conditions. The same is true of Plat H1. The

TABLE 3.—*Organic food reserves in buckbrush at two-week intervals and the effectiveness of cutting at these dates, season of 1928.*

Date collected	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Total starch and dextrin	Hemicellulose	Fiber	Effectiveness of cutting stems*	Stage of growth
	%	%	%	%	%	%	%	%	
Apr. 10	0.57	2.64	2.04	3.36	5.40	21.68	44.35	—	Leaves appearing
Apr. 27	0.62	2.17	2.42	4.07	6.49	21.10	47.90	+6	Growth retarded by cold weather
May 8	0.50	1.92	3.08	4.73	7.81	20.52	44.18	+73	Full leaf, flower buds showing
May 22	0.33	2.02	2.70	4.24	6.94	20.27	46.65	+88	In full flower
June 7	0.38	2.35	6.10	3.25	9.35	18.70	42.37	+56	Through flowering
June 25	0.40	3.38	2.86	3.63	6.49	19.60	42.85	0	Vigorous growing condition
July 2	0.42	2.42	5.83	6.55	12.38	18.31	45.20	— 6	Vigorous growing condition
July 16	0.49	3.02	1.83	4.38	6.21	20.52	43.96	—25	Vigorous growing condition
July 30	0.66	2.78	1.27	4.87	6.14	19.30	38.19	—28	Vigorous growing condition
Aug. 13	0.54	2.92	2.48	6.93	9.41	19.28	44.18	—27	Vigorous growing condition
Aug. 29	0.59	2.38	3.54	9.02	12.56	19.35	40.50	—45	Vigorous growing condition
Sept. 10	0.59	2.90	2.70	9.35	12.05	19.06	40.84	—95	Leaves turning yellow, berries red
Sept. 24	0.65	2.53	3.08	10.12	13.20	18.65	38.80	—78	Leaves starting to fall

*Plus sign indicates percentage less than the original number of stems on plat; minus sign, percentage more than original number of stems on plat. Count of stems made June, 1929.

TABLE 4.—*Organic food reserves in sumac at two-week intervals and the effectiveness of eradication by cutting at these dates.*

Date collected	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Total starch and dextrin	Hemicellulose	Percentage effectiveness of cutting stems above ground*	Stage of growth
	%	%	%	%	%	%		
Apr. 10	0.56	6.71	2.00	4.14	6.14	17.75	—	
Apr. 23	0.94	6.23	2.62	6.10	8.72	17.44	—	
May 8	1.03	4.51	4.47	8.52	12.99	16.79	+32	Leaves starting to show
May 21	0.85	5.17	2.85	5.64	8.49	18.28	+43	Leaves 2/3 mature
June 7	0.62	4.04	1.68	1.65	3.33	19.94	+60	Leaves fully out, flower buds showing
June 25	0.54	5.23	5.18	8.25	13.43	16.44	+10	About through flowering
July 2	0.65	4.68	5.61	12.51	18.12	14.84	+42	Seed fully formed
July 16	0.68	6.10	2.59	7.84	10.43	16.42	—60	
July 30	0.75	7.76	2.45	13.70	16.15	13.29	—98	
Aug. 13	0.84	3.63	2.48	10.50	12.98	14.87	—108	Vigorous growth
Aug. 29	1.12	7.16	2.67	10.38	13.05	13.90	—75	
Sept. 10	0.77	5.31	1.85	11.31	13.16	17.29	—81	Leaves turning red, starting to drop
Sept. 24	0.64	5.14	2.03	9.69	11.72	16.88	—52	Leaves all dropped

*Plus sign indicates percentage less than original number of stems; minus sign, percentage more than original number of stems. Counts yield of vegetation from the plats is indirectly proportional to the frequency of cutting. These data indicate that the food reserves increase with the lengthening of the period of protection, particularly during the beginning of the season. The protection during the latter part of the season apparently is not so helpful, as is shown by the data on plat CV12. In none of the plats were the organic food reserves equal to those of the untreated or check plat.

The investigations on the organic food reserves in the weeds and brush were conducted in connection with the cuttings of these plants to determine not only the amount of food reserves at different periods during the growing season, but also any correlation which might exist between the amount of reserve food and the effectiveness of cutting.

BUCKBRUSH

The data for buckbrush are presented in Table 3.

The correlation between the total food reserves in buckbrush and the effectiveness of eradication by cutting the stems above ground is not very striking, yet there is a correlation between the nitrogen and total sugars and the effectiveness of eradication. The poor correlation may be due to inability to secure samples from plants of uniform age.

SUMAC

The data on food reserves in sumac and the effectiveness of eradicating by cutting the stems above ground is contained in Table 4. These data are for the season of 1928.

These data show in general an increase in all the reserves, with the exception of the total sugars and hemicellulose, for the first month or until the leaves start to come out, when there is a very sharp decrease which is lowest June 7 or about the time the flower buds appear. After this the food reserves increase and remain rather high for the remainder of the season. There is a good correlation between the quantity of food reserves and the effectiveness of eradication. The effectiveness of eradication is inversely proportional to the quantity of the organic food supply.

VERVAIN

The food reserves for vervain are shown in Table 5.

This plant appears to store very little food reserve in the form of starch. Sections cut from the roots failed to show starch when treated with iodine. Not considering the hemicellulose, the sugars appear to represent the major portion of the food reserves. The percentage of sugar also correlates fairly well with the stages of

TABLE 5.—*Organic food reserves in vervain roots collected at two-week intervals, season of 1928.*

Date collected	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Total starch and dextrin	Hemicellulose	Stage of growth
	%	%	%	%	%	%	
Apr. 10	0.82	6.10	1.39	0.38	1.77	18.43	Leaves showing
Apr. 23	1.09	4.82	1.39	0.54	1.93	23.13	
May 8	0.85	2.89	2.09	1.65	3.74	24.20	Stems 3 inches high
May 21	0.73	2.06	1.02	0.98	2.00	24.40	Stems 8–14 inches high
June 7	0.82	2.01	1.82	0.82	2.66	22.90	Bud stage
June 21	0.64	1.27	1.55	0.64	2.19	25.30	Starting to flower, stems 36 inches high
July 2	0.53	2.12	1.55	0.71	2.26	26.80	Full flower
July 16	0.46	2.14	0.75	0.54	1.29	26.60	2 3 through flowering
July 30	0.90	1.99	0.59	0.44	1.03	24.70	
Aug. 13	0.56	3.60	1.28	1.07	2.35	24.00	
Aug. 29	0.68	3.10	1.02	0.54	1.58	26.60	Through flowering, leaves drying at base
Sept. 10	0.64	4.82	1.44	0.87	2.31	22.00	Leaves dead, stems 2 3 dead
Sept. 24	0.63	7.49	1.93	0.51	2.44	22.30	

TABLE 6.—*Organic food reserves in iron weed roots and the effectiveness of eradication by cutting the stems above ground, season of 1928.*

Date collected	Nitrogen	Total sugars	Dextrins and water-soluble starch	Starch	Starch and dextrin	Hemicellulose	Effectiveness of cutting stems*	Stage of growth
	%	%	%	%	%	%		
July 2	0.61	4.79	3.58	1.65	4.23	15.68	+18	Stem 43 inches
July 16	0.57	5.00	1.30	0.62	1.92	17.45	+45	Bud stage
July 30	0.52	4.84	1.65	1.73	3.38	16.42	+16	Starting to flower
Aug. 13	0.71	4.29	2.12	2.28	4.40	14.27	+10	Full flower
Aug. 29	0.62	3.58	2.61	1.84	4.45	13.38	+10	Through flowering
Sept. 10	0.92	3.81	1.65	2.09	3.74	17.23	0	1 3 of stems and leaves dead
Sept. 24	0.52	3.62	1.41	5.09	6.50	23.43	—36	All stems and leaves dead

*Plus sign indicates percentage less than original number of stems; minus sign, percentage more than original number of stems. Counts Made June, 1929.

growth, decreasing in general until the plant is in flower when the depleted supply is restored gradually until the close of the season. No cutting plats were established for this weed, but extensive work in mowing pastures indicates that the most effective time for cutting is about the time the plant starts to flower, which is also the time the sugar content is least.

IRON WEED

The analyses for iron weed are contained in Table 6, the collection of samples of this weed were unfortunately not started until July 1928.

In the iron weed, as was true of the vervain, the most effective time of cutting is in the bud stage. At this time, the plant has the least amount of starch and dextrins as well as the other reserves, excluding the hemicellulose.

CONCLUSIONS

These data indicate that perennial herbacious plants decrease in organic reserves up to about the time of flower, after which the plants begin to restore the reserves which must have been drawn on to produce the top growth.

From the work done, it appears that the data on organic food reserves will be helpful in determining the growing requirements of pasture plants and in knowing how to maintain or increase the vigor and productivity of desirable species. The information will also be equally valuable in planning the eradication of worthless plants by showing the season when these plants have the least resistance to eradication methods.

To make the data more accurate, it would be desirable to have improved methods for obtaining more uniform samples and for making the analyses in order to measure more accurately the differences and quantity of the food reserves.

EFFECT OF SOIL TYPE AND FERTILIZER ON THE NITRATE CONTENT OF THE EXPRESSED SAP AND THE TOTAL NITROGEN CONTENT OF THE TISSUE OF THE SMALL GRAINS[1]

R. L. Cook[2]

An examination of the available literature reveals considerable information regarding the effect of fertilization and stage of growth on the nitrogen content of wheat, rye, barley, and oats, but fewer facts as to the nitrate content of the expressed sap of these plants. In view of this situation it was deemed advisable to endeavor to ascertain the effects of soil type, soil fertilization, and stage of growth on the nitrate content of the sap of these plants. Since it appears that at least a part of the nitrogen entering the roots of plants is in the nitrate form, there may be some correlation between the rate of growth, stage of growth, and the nitrate content of plants.

REVIEW OF LITERATURE

McCool and Weldon (5)[3] have shown that when the growth of plants is limited, due to lack of available phosphorus or potassium in the soil, that element which is plentiful in the soil becomes more concentrated in the sap.

Workers at the Rhode Island Experiment Station (7) have found that the amounts of nitrate nitrogen, phosphorus, and potassium in the juices of plants are correlated with the amounts of these substances added to the soil. Shortly after a period of high rainfall, resulting in a decrease of nitrate in the soil, very low levels of nitrate were obtained in the sap. At the same time, high levels of phosphorus and potassium were found.

Gilbert and Hardin (3), working with cabbage, lettuce, beets, and celery, found the nitrate nitrogen in the sap to increase with additions of nitrate to the soil. The total nitrogen content of the plants correlated quite well with the nitrate nitrogen present.

Determinations of nitrate nitrogen in weeds by certain workers have shown the concentration of this form of nitrogen to change considerably during different stages of growth. Woo (10) observed that the nitrate content of *Amaranthus retroflexus* increased from early stages until blooming. He assumed from this that it would continue to increase until maturity. Campbell (1), however, found the nitrate content of this weed to be highest at early blooming, but it contained none at maturity. He obtained similar results with rye and six species of weeds growing with the rye.

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[2] Research Assistant in Soils.

[3] Reference by number is to "Literature Cited," p. 407.

Duley and Miller (2) reported the percentage of nitrogen in corn plants to be higher when the plants are receiving large amounts of nitrogen as fertilizer. In cases where a liberal amount of nitrogen was available there was an accumulation of it in the plants. The percentage of nitrogen in the leaves, roots, and stalks decreased gradually from the first to the last part of the growth period.

Wilfarth, Roemer, and Wimmer (9) reported decreases in the nitrogen content of wheat, barley, and potatoes during successive stages of growth Ince (4) and Schweitzer (8) reported similar results from their studies with corn.

PROCEDURE

The present investigations were carried out on two outlying soil fertility fields and on special plats receiving varying amounts of nitrate of soda.

On the wheat and oat plats nitrogen was applied in the form of urea, phosphorus as superphosphate, and potassium in the form of potassium chloride. All these plats were limed. On the barley plats ammonium sulfate, superphosphate, and potassium chloride were used, and no lime was applied. The nitrogen was applied on the wheat plats both in the fall and in the spring.

Samples of the winter grains were taken once in the fall of 1927 and three times in the spring and summer of 1928. The spring grains were sampled at three different times. This procedure was expected to indicate the influence of soil type, fertilizers, and stage of growth on the nitrate content of the sap.

An attempt was made to gather and care for the samples so that a correct determination of the nitrate content of the sap at the time of sampling would result. Nightingale (6), working with tomato plants, found that the period of daily illumination caused variations in the carbohydrate and nitrogen content of the plants. From this, one might expect the hour of the day at which samples were taken to exert an influence on the composition of the sap. Therefore, the samples were gathered at as nearly the same hour of the day as possible.

To insure further uniformity throughout the investigations the samples were not gathered during rainy days nor when the plats were wet with dew.

All samples were cut at the surface of the ground and packed at once into glass jars. During warm weather the containers were packed in ice immediately after the samples were cut.

ANALYTICAL METHODS

As soon as possible after the samples were taken, the material on which nitrate determinations were to be made was ground in a food chopper. The ground tissue was then wrapped in a single layer of new cheesecloth, placed in a steel cylinder of 8 cm diameter, and subjected to a pressure of 1 ton until the juice ceased to flow.

As soon as the juice was obtained it was centrifuged for 10 minutes to remove small pieces of tissue or other solid particles.

All nitrate determinations were made as follows: A portion of the centifuged juice, usually 10 cc, was pipetted into a 100-cc centrifuge tube. An amount of saturated lead subacetate solution, equal to 40% of the amount of sap, was added and the volume made up to 100 cc. After thorough stirring, it was then centrifuged for 10 minutes to remove chlorophyll and other organic materials. After centrifuging, the supernatant liquid was poured off, shaken with 5 grams of "norite," a wood charcoal, and filtered. The filtrate was treated once more with 3 grams of "norite" and passed again through the same filter. Fifty cc of the filtrate were placed in an 80-cc test tube and heated to boiling with an excess of Ag_2SO_4,$CuSO_4$, $MgCO_3$, and CaO After cooling, the solution was made up to volume, shaken with 1 gram of "norite," and filtered through a hard filter paper. This was sufficient treatment to remove organic matter and chlorides. Duplicate 25-cc portions of the filtrate were then evaporated to dryness on the steam bath. Nitrate was determined by the phenoldisulfonic acid method.

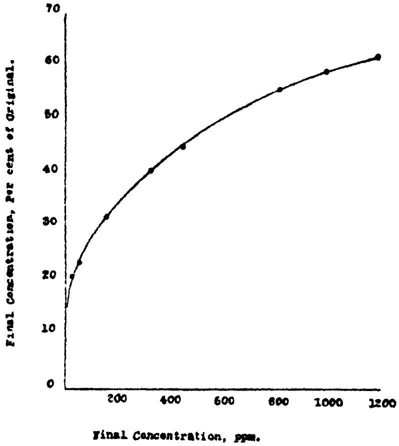

FIG. 1 —Curve showing the percentage of nitrate recovered.

It was found that during this procedure considerable nitrate was removed from solution. A series of known solutions containing varying concentrations of nitrate were therefore analyzed. The results obtained showed that the nitrate recovered was a function of the original concentration of nitrate in the known solutions. The graph shown in Fig. 1, constructed from these data, was used to correct the analytical results.

Moisture in the green sample was determined by weighing out a large sample, usually 100 grams, drying in a well-ventilated oven at 45° to 55°C, and reweighing.

EXPERIMENTAL RESULTS

The plants used in these studies were grown on the general fertility plats receiving fertilizers as described above, and on special plats treated with varying amounts of sodium nitrate.

OATS

The data in Table 1 were obtained from oats grown on Miami loam. It is to be noted that the applications of phosphate and potash reduced the nitrate content of the sap. The greatest effect occurred during the periods of rapid growth as evidenced by the June 1 and June 27 samplings. On June 1 the sap of the plants treated only with phosphorus and potash contained about two-thirds as much nitrate as did the plants receiving no fertilizer. It is also apparent that at this sampling nitrogen applications measurably increased the nitrate content of the sap In all cases there was more nitrate in the sap of the plants treated with nitrogen than in those receiving only the non-nitrogenous fertilizers.

TABLE 1.—*The effect of fertilizer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of oats grown on Miami loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		June 1, 1928		
Lime.......	1,470	5.48	6.46	46.0
Lime N....	1,620	5.98	6.35	47.3
Lime P....	1,070	5.44	5.58	55.8
Lime NP...	1,460	5.97	6.69	59.3
Lime PK...	1,040	—	—	61.9
Lime NPK..	1,390	5.72	6.82	79.2
		June 27, 1928		
Lime.......	267	3.38	6.58	—
Lime N.....	125	2.80	6.68	—
Lime P.....	94	2.65	6.81	—
Lime NP...	133	2.76	6.58	—
Lime PK...	102	2.25	6.93	—
Lime NPK..	136	2.40	6.94	—
		July 13, 1928		
Lime.......	140	1.67	3.17	—
Lime N.....	140	1.49	3.22	—
Lime P.....	115	1.27	3.22	—
Lime NP...	175	1.58	2.96	—
Lime PK..	122	1.53	2.85	—
Lime NPK..	142	1.52	2.93	—

*N, P, and K were applied as urea, superphosphate, and potassium chloride, respectively.

The results presented in Table 2, obtained from another field of Miami loam, show again the effect of applications of phosphate and potash to this soil type. On July 24, the nitrate content of the sap of oat plants was 73 p.p.m., whereas it was 812 in the sap of the plants growing on the untreated soil. Similar results were obtained in the two earlier samplings. The effects of the nitrogen in some of the mixtures were not consistent, no doubt due to the fact that the fertilizers were applied to the crop preceding the oats.

TABLE 2.—*The effect of fertilizer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of oats grown on Miami loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		June 15, 1928		
Check	1,230	4.66	5.12	32.3
PK	942	4.22	5.48	51.5
NK.....	1,170	4.82	5.40	32.8
N (P 400).	1,640	4.83	6.35	50.5
N (P 200) K	870	5.54	5.95	47.6
N (P 400) K	980	4.65	5.95	57.2
N (P 600) K	760	4.86	5.83	60.4
		July 6, 1928		
Check	547	3.03	5.28	——
PK.......	156	2.16	6.69	——
NK	150	2.06	6.81	——
N (P 400).	149	2.03	5.20	——
N (P 200).	147	2.58	5.41	——
N (P 400) K	67	1.97	6.69	——
N (P 600) K	184	0.85	6.94	——
		July 24, 1928		
Check ..	812	1.76	2.91	——
N (P 600) K	73	1.13	2.56	——

*Fertilizers were applied for sugar beets the preceding year and were not repeated for the oats. No lime was applied.

TABLE 3.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of oats grown on Miami loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		June 4, 1928		
0	34	3.98	6.37	53.7
50	495	4.82	6.37	46.8
100	700	4.91	6.25	48.1
150	815	5.50	6.57	59.0
		June 27, 1928		
0	97	1.72	6.04	——
50	93	2.30	6.41	——
100	89	1.84	6.13	——
150	92	1.85	6.46	——
		July 17, 1928		
0	92	1.05	2.53	——
50	95	1.04	2.46	——
100	88	1.03	2.39	——
150	92	1.15	2.56	——

Very striking results were obtained from the nitrate treatments applied to oats grown on Miami loam. As shown by the data given in Table 3, the yield of grain was high on all plats including the checks, thus showing that nitrogen was not a limiting factor on this field. Regardless of the plentiful supply of available nitrogen, the application of sodium nitrate increased the nitrate in the sap on June 4 from 34 to 815 p.p.m. This would seem to show that in early growth this plant can accumulate a large amount of nitrate in addition to that which is needed.

Fertilizers caused variations in the nitrate content of the sap of plants grown on Hillsdale sandy loam. According to field trials the yields of several crops on this soil are increased by applications of potash. An examination of the data in Table 4 shows that in every case the plants treated with potash contained less nitrate in the sap than did plants receiving no fertilizer or fertilizers other than potash. As shown above with plants on Miami soil, the addition of nitrogenous fertilizers caused increases in the nitrate content of the sap.

TABLE 4.—*The effect of fertilzer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of oats grown on Hillsdale sandy loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 31, 1928		
Check . ..	795	6.05	5.25	46.5
Lime	810	5.40	5.95	47.4
Lime P . .	810	5.10	6.69	45.8
Lime NP...	920	5.85	6.46	52.6
Lime PK ..	302	6.33	6.58	54.2
Lime NPK	535	5.67	7.63	54.1
		June 22, 1928		
Check......	89	3.26	6.47	——
Lime... ...	85	2.48	6.20	——
Lime N.....	116	2.86	6.47	——
Lime P....	63	2.04	5.71	——
Lime NP...	99	2.42	6.23	——
Lime PK .	47	1.92	6.05	——
Lime NPK..	76	1.97	6.20	——
		July 12, 1928		
Check......	155	1.19	2.99	——
Lime	150	1.09	2.72	——
Lime N.....	192	1.50	2.70	——
Lime P.....	144	1.23	2.37	——
Lime NP...	170	1.18	2.57	——
Lime PK .	51	0.86	2.41	——
Lime NPK..	105	1.09	2.28	——

*N, P, and K were applied as urea, superphosphate, and potassium chloride, respectively.

Table 5 presents results obtained on a depleted Hillsdale sandy loam soil. These results are in contrast to those found on the Miami soil in that nitrate applications did not increase the nitrate content of the sap. This shows that the plants cannot accumulate nitrate in the sap unless there is an excessively large supply of available nitrogen in the soil.

TABLE 5.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of oats grown on Hillsdale sandy loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
June 11, 1928				
0	950	5.75	5.66	31.8
50	1,130	5.94	6.46	38.7
100	975	7.65	5.85	36.8
150	870	5.71	6.46	37.8
July 5, 1928				
0	147	1.90	4.62	——
50	118	2.38	5.71	——
100	112	2.32	5.67	——
150	106	2.44	6.19	——
July 19, 1928				
0	127	1.36	2.70	——
50	171	1.49	2.75	——
100	132	1.50	2.76	——
150	117	1.46	2.98	——

BARLEY

Barley, as illustrated by Tables 6 and 7, gave results similar to those for oats. It is to be noted that in 8 out of 10 cases wherever growth, as indicated by the yields, was increased by fertilizer applications other than nitrogen, the nitrate content of the expressed sap was decreased. With one exception, the addition of nitrogen to the fertilizer increased the nitrate content of the sap, showing again the effect of applications of available nitrogen to the soil.

TABLE 6.—*The effect of fertilizer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of barley grown on Miami loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
May 22, 1928				
Check......	600	5.60	8.44	17.7
P........	450	4.57	6.82	18.7
PK........	535	5.83	8.72	19.3
NPK.......	505	5.12	6.35	22.3
June 21, 1928				
Check......	61	2.59	6.62	——
P..........	72	2.38	6.62	——
PK........	42	1.79	5.53	——
NPK.......	46	1.70	5.21	——
July 13, 1928				
Check......	100	1.13	2.73	——
P..........	85	0.96	2.56	——
PK........	88	0.76	——	——
NPK.......	96	0.84	1.86	——

*N, P, and K were applied as ammonium sulfate, superphosphate, and potassium chloride, respectively. No lime was applied.

TABLE 7.—*The effect of fertilizer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of barley grown on Miami loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 22, 1928		
Check......	760	5.32	5.25	27.3
P.........	895	5.80	5.85	35.8
PK.......	655	5.71	6.14	27.0
NPK.......	1,090	6.07	6.57	43.3
		June 20, 1928		
Check	169	2.90	5.15	——
P.........	107	2.42	4.95	——
PK	70	1.90	4.46	——
NPK.	106	2.26	4.97	——

*N, P, and K were applied as ammonium sulfate, superphosphate, and potassium chloride, respectively.

TABLE 8.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of barley grown on Miami loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 23, 1928		
0	1,390	6.14	5.76	32.2
50	1,320	5.56	6.14	41.3
100	1,450	6.87	6.82	35.6
150	1,060	5.97	6.34	35.2
		June 20, 1928		
0	151	2.82	5.33	——
50	330	2.76	5.33	——
100	284	2.59	4.95	——
150	266	4.02	5.21	——

TABLE 9.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of barley grown on Hillsdale sandy loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		June 11, 1928		
0	560	5.67	5.15	11.6
50	705	5.72	5.95	18.1
100	645	5.71	5.55	19.3
150	850	5.88	6.40	22.9
		July 5, 1928		
0	159	1.98	4.16	——
50	157	2.10	4.16	——
100	159	2.04	4.05	——
150	121	1.90	——	——
		July 19, 1928		
0	83	1.43	2.95	——
50	92	1.55	2.72	——
100	75	1.28	2.18	——
150	141	1.48	2.35	——

Soil conditions may have considerable influence on nitrogen relationships, as evidenced by the results presented in Tables 8 and 9. Nitrogen treatments caused increases in the nitrate content of the sap of barley grown on both of these fields. On the Miami loam, however, the differences in the sap did not appear until the second sampling, while on the Hillsdale soil there were large differences in the nitrate content of the sap at the first sampling and very little later in the season. It is difficult to say what caused this, but since the two fields vary widely in texture, soil moisture may have had something to do with it. The spring of 1928 was very cold and wet. Excess water held in the Miami soil might have caused slower nitrification, thus preventing the plants from getting a supply of nitrogen before the nitrate was applied.

WHEAT

The data in Table 10 were obtained from wheat grown on Miami loam. It is to be noted that, with the exception of the autumn sampling, the applications of phosphate and potash reduced the nitrate content of the sap. As with oats, the greatest effect occurred during the period of very rapid growth.

TABLE 10.—*The effect of fertilizer applications on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of wheat grown on Miami loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		November 26, 1927		
Lime	188	4.66	3.14	——
Lime N. . .	——	5.58	4.38	——
Lime P ...	220	3.88	2.93	——
Lime NP. .	194	4.86	3.35	——
Lime PK. . .	203	4.80	4.52	——
Lime NPK. .	——	4.96	4.08	——
		June 8, 1928		
Lime ...	193	3.19	3.68	——
Lime N. . .	113	2.23	3.05	——
Lime P .	110	2.88	3.81	——
Lime NP. .	145	2.50	3.21	——
Lime PK	91	1.45	3.19	——
Lime NPK.	118	1.91	3.24	——
		June 28, 1928		
Lime	215	1.26	2.23	——
Lime N.	198	1.10	2.67	——
Lime P ...	114	1.25	——	——
Lime NP. . .	——	——	2.32	——
Lime PK. . .	151	1.06	——	——
Lime NPK. .	184	1.07	2.21	——

*N, P, and K were applied in the form of urea, superphosphate, and potassium chloride, respectively.

Investigations with wheat grown on Hillsdale sandy loam as indicated by the data presented in Table 11 verify the results obtained from oats on that soil. The nitrate content of the sap tended to be low on all plats treated with potash in all stages of growth, although the differences were larger during the early stage. This is to be expected in the light of Campbell's work on rye and weeds, to which reference was made above. It is also apparent that nitrogen applications, on the other hand, measurably increased the nitrate content of the sap.

TABLE 11.—*The effect of fertilizer application on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of wheat grown on Hillsdale sandy loam.*

Treatment*	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams
	November 29, 1927		
Check	115	4.64	3.58
Lime	109	4.68	3.46
Lime N	161	5.14	3.94
Lime P	240	5.22	3.69
Lime NP	188	4.94	4.32
Lime K	74	4.60	4.10
Lime NK	118	4.64	3.81
Lime PK	76	4.14	3.61
Lime NPK	99	4.44	4.01
	May 7, 1928		
Check	281	4.20	3.10
Lime	292	3.72	2.90
Lime N	274	3.53	3.04
Lime P	288	3.80	2.97
Lime NP	270	4.14	3.24
Lime K	224	3.59	3.13
Lime NK	270	3.93	2.73
Lime PK	267	3.06	3.24
Lime NPK	286	4.01	3.06
	June 7, 1928		
Check	249	1.31	3.28
Lime	245	1.58	3.33
Lime N	288	1.37	3.43
Lime P	267	1.31	3.00
Lime NP	309	1.30	3.44
Lime NK	213	1.42	3.64
Lime PK	236	1.44	3.19
Lime NPK	330	1.12	3.26
	July 2, 1928		
Lime	305	0.84	1.79
Lime N	300	1.02	——
Lime P	239	——	1.74
Lime NP	340	0.78	1.64
Lime K	268	0.80	——
Lime NK	345	0.78	——
Lime PK	221	0.86	1.95
Lime NPK	305	0.75	1.70

*N, P, and K were applied as urea, superphosphate, and potassium chloride, respectively.

A study of Table 12 reveals an increase in yield of wheat grown on Miami loam soil resulting from the application of sodium nitrate. The nitrate content of the sap was likewise augmented. This was less obvious in the later stages, however, than in the early stage.

This was due, no doubt, to the fact that the period of rapid growth had been passed on this particular field, before the June 8 sampling.

TABLE 12.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of wheat grown on Miami loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 10, 1928		
0	292	3.61	2.90	31.7
50	390	3.76	3.39	33.4
100	396	4.02	3.63	39.0
150	370	4.05	3.54	36.7
		June 8, 1928		
0	209	1.97	3.58	——
50	202	2.01	3.74	——
100	278	1.65	3.42	——
150	174	1.86	3.54	——
		June 27, 1928		
0	197	1.40	2.24	——
50	220	1.26	2.21	——
100	237	1.13	1.80	——
150	203	1.02	1.98	——

As represented by the data in Table 13, the application of sodium nitrate to a Hillsdale sandy loam soil increased the nitrate content of the sap from 189 to 277 p.p.m. during the early part of the growth period.

TABLE 13.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of wheat grown on Hillsdale sandy loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 7, 1928		
0	189	3.17	2.97	27.4
50	215	3.16	2.94	27.9
100	277	3.19	3.35	31.9
150	274	3.59	3.38	33.1
		May 31, 1928		
0	146	1.18	2.93	——
50	164	1.56	3.55	——
100	146	1.62	3.59	——
150	154	1.48	3.27	——
		June 22, 1928		
0	151	0.94	2.16	——
50	159	1.01	2.38	——
100	138	0.94	2.39	——
150	166	0.93	2.02	——

RYE

Rye grown on Miami loam, according to the data in Table 14, gave results similar to those obtained from the other crops except that the differences were apparent later in the development of the plants. This may also have been due to the high moisture content of this soil during the month of April. It was very wet at that time and the plants were no doubt starving for nitrogen when the nitrate was applied. This would prevent an early accumulation of nitrate nitrogen in the expressed sap.

TABLE 14.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of rye grown on Miami loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 9, 1928		
0	540	4.81	4.15	10.6
50	480	4.28	3.86	11.7
100	—	4.64	3.95	14.0
150	515	4.68	4.00	13.8
		June 12, 1928		
0	167	2.06	3.85	—
50	170	2.98	4.40	—
100	306	2.57	4.52	—
150	355	—	4.88	—
		July 3, 1928		
0	191	1.17	2.13	—
50	274	1.64	2.38	—
100	235	1.32	2.01	—
150	263	1.50	2.32	—

On Hillsdale sandy loam soil, as shown by the results in Table 15, the nitrate content of the sap of rye paralleled the yields but not the nitrate applications to the soil. Because of a sag in the field, the plat receiving the heavy nitrogen application was rather poorly drained. This might have decreased the nitrate content of the soil which would cause a decrease in the nitrate content of the sap.

TABLE 15.—*The effect of nitrate fertilizer on the total nitrogen content of the tissue and the nitrate nitrogen content of the expressed sap of rye grown on Hillsdale sandy loam.*

Sodium nitrate in pounds per acre	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Yield of grain per acre, bushels
		May 9, 1928		
50	276	2.93	4.00	40.0
100	330	3.20	4.21	52.2
150	228	2.93	3.80	42.2
		June 12, 1928		
50	190	1.01	5.53	—
100	228	0.94	5.76	—
150	170	1.01	6.14	—

TOTAL NITROGEN

An examination of all these data on all crops and soil types shows that in general the total nitrogen content of the dried tissue paralleled quite closely the nitrate content of the sap. There were very few exceptions to this at the first sampling, although during the later periods of growth the results were less consistent. In the case of wheat and rye it might even be said that there was no correlation between the total nitrogen in the dried tissue and the nitrate in the sap during the latter part of the season, except that they were both at a low level during this period. This is not surprising, however, because the differences in nitrate in the sap during the latter part of the season were very small and were less consistent than during early growth.

In oats and barley there was a close correlation between the nitrogen in the dried tissue and the nitrate content of the expressed sap at all stages of growth.

Since it was found that increased growth due to the addition of some fertilizer element other than nitrogen tended to decrease the nitrate in the sap, as the above results indicate, the same thing should be true as regards total nitrogen. The higher quality of the crops studied, as regards either potassium, calcium, or phosphorus content, may be obtained by fertilizer applications at the expense of the protein content. As the nitrate plats have shown, this condition may be avoided by the addition of some form of soluble nitrogen.

RATIO OF LEAVES TO STEMS

The question came up quite early in the work as to whether or not some of the results found may have been due to differences existing in leaves and stems. Table 16 shows that the stems usually contained more nitrate and less total nitrogen than did the leaves.

TABLE 16.—*A comparison between the total nitrogen content of the leaves and that of the stems, and between the nitrate nitrogen content of the leaves and that of the stems of rye, wheat, barley, and oats.*

Material	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue, %	Water per gram of dry weight, grams
Rye:			
Leaves	194	1.86	2.04
Stems	142	0.67	1.89
Wheat:			
Leaves	134	3.77	4.33
Stems	331	1.52	3.99
Barley:			
Leaves	200	4.27	5.66
Stems	229	2.28	6.40
Oats:			
Leaves	285	4.56	4.98
Stems	407	2.84	4.32

This discovery led to a study of the proportion of leaves to stems on different sized plants. If this proportion were different where the growth was small, as on the check plats, from that where the plants were larger, as in case of fertilized plats, it might explain some of the results obtained. The data given in Table 17 reveal the fact that the proportion of leaves to stems did not vary consistently on check and fertilized plats. Oat plants had only 1% more leaves on the check plat than on the fertilized plat. These samples were collected on Miami loam where the check plat gave 32.3 bushels per acre and the fertilized plat 60.4 bushels per acre.

TABLE 17.—*A comparison of fertilized and unfertilized plants as to the total nitrogen content of the tissue, the nitrate nitrogen content of the expressed sap, and the relative weight of leaves and stems, June 9–10, 1928.*

Treatment and material	Nitrate nitrogen in sap, p.p.m.	Total N in dry tissue %	Water per gram of dry weight, grams	Total weight of the green plants, %
		Oats		
NPK, leaves	63	1.97	4.44	33.28
NPK, stems	75	0.63	5.45	66.72
Check, leaves	260	3.78	5.50	34.70
Check, stems	313	1.49	6.75	65.70
		Barley		
NPK, leaves	103	1.37	1.53	26.00
NPK, stems	92	1.49	1.90	74.00
Check, leaves	116	1.73	1.94	30.30
Check, stems	168	0.50	1.69	69.70
		Wheat		
NPK, leaves	315	0.72	0.80	11.90
NPK, stems	328	0.60	1.38	88.10
Lime, leaves	278	3.27	1.52	18 00
Lime, stems	328	1.07	1.74	82.00
		Rye		
$NaNO_3$, leaves	—	1.68	1.04	11.80
$NaNO_3$, stems	—	0.82	1.58	88.20
Check, leaves	—	1.76	1.12	9.00
Check, stems	—	0.76	1.59	91.00

Barley and wheat gave 4 and 7%, respectively, more leaves on the check plats than on the fertilized plats. The leaves of the fertilized plants had less moisture at the time of sampling than did those of the untreated plants, due to the fact that the fertilized plants were more nearly mature. Less moisture in the leaves would, of course, cut down the weight of leaves on the fertilized plants. Taking this into consideration, it may be said that there were no appreciable differences in the proportion of leaves to stems.

Rye had about 3% less leaves on the untreated plants than on the treated plants. This is the reverse of the condition found in the other three crops.

SOIL TYPE

The data presented in Tables 1 to 15, inclusive, furnish a means of studying the effect of soil type on nitrate in the expressed sap and total nitrogen in the dried tissue. In three cases Miami loam produced plants having higher nitrate and total nitrogen levels than did

Hillsdale sandy loam. In two cases the condition was reversed.

Results were obtained from two fields of oats and barley on Miami loam. In both cases the field giving the higher average yield of grain gave the higher nitrate and total nitrogen levels.

A comparison of the state of fertility of each individual field, as indicated by the yield of grain, with the analytical results obtained during the investigations, indicates that the state of fertility has more influence on the nitrate and total nitrogen content of the crop than does soil type. While natural fertility is largely dependent upon soil type, it is a condition that is easily but temporarily changed by agricultural practices.

CONCLUSIONS

Any fertilizer, with the exception of nitrogen, that increased plant growth had a tendency to decrease the nitrate content of the expressed sap. Nitrogen fertilizers tended to increase the nitrate content of the sap.

The total nitrogen content of the dried tissue varied directly with the amount of nitrate in the sap.

The stems, as a general rule, contained more nitrate nitrogen in the sap and less total nitrogen in the tissue than did the leaves of the same plants

The size of the plants of the small grains seemed to make no difference in the proportion of stems to leaves.

The spring grains possessed greater ability to accumulate nitrate in the sap than did the winter grains.

The total nitrogen in the tissue, regardless of fertilizer treatment, declined steadily throughout the growing season

The state of fertility of the soil had more effect than soil type on the nitrate content of the sap and the total nitrogen content of the tissue of the small grains.

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WEED PROBLEMS IN RELATION TO THE PRODUCTION AND MARKETING OF FARM SEEDS[1]

H. C. RATHER[2]

Weeds present an agricultural problem as old as time and as new as today. With old-fashioned weapons and by the sweat of the brow, the earliest farmers battled to save their crops from the onslaught of enemy plants. With much the same sort of weapons and by dint of the same hard labor, the farmer of today struggles against a seemingly increased host of these same enemies.

The weed problem is attracting new and rather wide attention, on the part of several interests. The farmer, of course, is vitally concerned, and anything new by way of weed control measures attracts his immediate attention. The state is interested, and many states have weed laws, while nearly all have seed laws dealing with the weed problem.

Naturally, every seedsman is interested, as weeds directly affect his cost of doing business and the quality of his product. Closely associated with the seedsmen's interest is that of the commercial and the official seed analysts seeking to evaluate seed largely on the basis of its freedom from or contamination with the seed of weeds.

The implement manufacturer is interested in building and selling more effective weed control machinery. Manufacturers of seed-cleaning equipment have the same end in view. More recently, chemical companies have been taking a major interest in weeds, while railroads and banks of some sections, recognizing in agriculture their chief means of support, are contributing time and money to weed control efforts.

The Seed Council of North America, an organization of groups interested in farm seeds with which this Society is associated, has undertaken something of a study of weed and seed laws and has before it at present some resolutions which have an important bearing on our attitude toward noxious weeds. And, finally, the United States Chamber of Commerce, through its agricultural committee, is seeking to bring together many of these interests for a thorough study of the weed problem and, if feasible, for a concerted drive against weed losses.

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[1] Contribution from the Department of Farm Crops, Michigan State College, East Lansing, Mich. Presented at the annual meeting of the Society held in Chicago, Illinois, November 15, 1929.

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With new activity on the part of many of the above-named interests, the botanist and agronomist, who have already worked a great deal along the lines of weed control, are likely to have increased demands made upon them for weed information, and it is of real importance to agriculture that no bushel be left unturned that may hide some ray of light on this genuine farm problem.

Going to one very obvious source of weed difficulties, crop seed, the records were examined on some 200 lots of alsike, June, and mammoth clover which came from nearly every clover seed producing section of Michigan.

The story of what happens to the average 100 pounds of clover seed after it leaves the farm is interesting. Tables 1, 2, and 3 are compiled from the averages of 85 farm lots of June clover, 35 of alsike, and 73 of mammoth, and give some idea of cleaning charges and shrinkage which clover seed incurs before it is really ready for the market.

TABLE 1.—*Shrinkage, costs, and farm returns on 100 pounds of thresher-run red clover seed containing buckhorn.*

	Pounds of seed	Shrinkage		Cleaning costs, cents	
		%	Pounds	Rate per bushel	Actual cost
Original weight of seed from thresher	100				
Cleaning 1st run		19.48	19.48	30	50
Amount seed left after 1st run	80.52				
Special cleaning to remove buckhorn		6.26	5.04	70	94
Clean seed	75.48				

The value of this seed based on $18 per cwt. farm price for cleaned seed is $13.59. The net value, after deducting cleaning costs, is $12.15.

TABLE 2.—*Shrinkage, costs, and farm returns on 100 pounds of thresher-run mammoth clover seed.*

	Pounds of seed	Shrinkage		Cleaning costs, cents	
		%	Pounds	Rate per bushel	Amount
Lot A, needing special cleaning to remove buckhorn					
Original weight of seed from thresher	100				
Cleaning 1st run		17.86	17.86	30	50
Amount of seed left after 1st run	82.14				
Special cleaning to remove buckhorn		7.6	6.24	70	96
Clean seed	75.9				
Lot B, needing no special cleaning to remove buckhorn					
Original weight of weed from thresher	100				
Cleaning 1st run		11.71	11.71	30	50
Amount of seed left after 1st run	88.29				
Clean seed	88.29				

Based on a farm price for clean seed of $18.00 per cwt., Lot A has a net value of $12.20 after deducting shrinkage and cleaning costs, while Lot B has a value of $15.39.

TABLE 3.—*Shrinkage, costs, and farm returns on 100 pounds of thresher-run alsike clover seed.*

	Pounds of seed	Shrinkage		Cleaning costs, cents	
		%	Pounds	Rate per bushel	Amount
Lot A, needing special cleaning to remove Canada thistle, timothy, and trace of quack grass					
Original weight of seed from thresher	100				
Cleaning 1st run		20.06	20.06	30	50
Amount of seed left after 1st run	79.94				
Special cleaning to remove Canada thistle, timothy, and some quack grass		6.36	5.08	70	93
Clean seed	74.86				
Lot B, needing no special treatment					
Original weight of seed from thresher	100				
Cleaning 1st run		16.16	16.16	30	50
Amount of seed left after 1st run	83.84				
Clean seed	83.84				

Based on a farm price for clean seed of $16.00 per cwt., Lot A has a net value of $10.55 after deducting shrinkage and cleaning costs, while Lot B has a value of $12.91.

Seed containing troublesome weeds not only needs extra cleaning but, as might be expected, its shrinkage is likely to be heavier during the first cleaning. This is indicated by a comparison of the lots of mammoth and alsike which needed special cleaning to remove certain weeds with the lots not needing such treatment. A similar comparison in the case of June clover was not made, since it was difficult to find any number of farm lots of June clover not needing special recleaning to remove buckhorn.

Cleaning costs and shrinkage, of course, are but items in the cost of producing clean seed. If the seed grower is to prosper, however, these costs must not be excessive. Quality seed produced in clean, well-cared-for fields shrinks but little in being prepared for the market, the low shrinkage in the lots examined being 3.72% for alsike, 3.88% for mammoth, and 5.15% for June clover.

With other lots, low quality seed, inert matter, and weed seeds made necessary the use of different screens and a stronger wind blast, even for the first cleaning, so that one 1,700-pound lot of alsike shrunk 45%, an 8,600-pound lot of mammoth containing a heavy infestation of bracted plantain shrunk 23%, and several smaller lots of June clover shrunk more than 50%.

The shrinkage, of course, is not all weeds, shrivelled seed, and inert matter. A few sample lots of screenings were analyzed and, while the number of samples was too small to give any more than a mere indication of what screenings contain, the amount of good seed lost with the shrinkage in seed cleaning is of genuine interest. Typical instances are given below:

Kind of seed cleaned	Principal weeds found	Percentage of crop seed lost in shrinkage	Quality of crop seed lost
Sweet clover	Green foxtail	16	Fair
Red clover	Quack grass	36	Good
Alsike	Night flowering catchfly	26.5	Good
Red clover	Buckhorn	41	Very poor
Red clover	Quack grass (also timothy)	61	Good
Sweet clover	Night flowering catchfly	60.5	Good
Red clover	Curled dock	11	Fair
Red clover	Field peppergrass	4.5	Good

The information as here given points out a problem rather than a solution to a problem. Thus far, it seems a lot more thought and energy have been expended in trying to find out how to clean weeds out of seed than to produce seed which contains no weeds in the first place. Conceding that one cleaning over good equipment is necessary under the best of conditions, the present average shrinkage and the attendant loss of good seed constitute too great a charge in the costs of clean seed production.

It should be possible to avoid much of the expensive recleaning, a bill which amounts to $70,000 annually on the Michigan clover seed crop just for cleaning charges. Add to this the value of the good seed lost in recleaning operations and the recleaning bill amounts to $130,000 to $150,000 annually on the June clover seed growing industry of one state, a tax which should be largely avoidable.

The question of how clean seed crops can be produced gives rise to certain other queries. Just how much thought is given by the farmer of today in killing off weed seeds that are in his soil? Isn't there a modern tendency to think of seedbed preparation as purely a mechanical job? Power machinery and hook-ups that do the entire job of preparing a seedbed in one operation are advocated. Isn't that sort of thing losing sight of the fact that seedbed preparation is biological as well as mechanical? Isn't it possible for a seedbed to be in fine tilth and yet harbor such an abundance of unsprouted weed seed that a satisfactory crop under some conditions may be impossible?

Two seedbeds were fitted for beans at the Michigan Experiment Station last May. Both had good crops of sweet clover plowed under, both were firm and well worked mechanically. One area was planted June 5, while the weed seeds in the other area were given a period of 8 or 10 days to sprout and get under way. This area was then harrowed to kill off the weed sprouts and seedlings. Throughout the summer this latter area did not require even hand hoeing to keep it clean, while in the first area the weeds got away from the hoeing job entirely and the crop was almost a failure. Many farmers have held that the best cultivation can be accomplished before the crop is planted. In the case of grain, forage, and small seed crops this is the only cultivation the crop gets. Are we to be contented with that oft-repeated injunction, "Prepare a firm, well fitted seedbed," or can we be more specific and tell quite exactly what operations are involved and how they should be applied in fitting a seedbed well? Our one hope of producing cleaner small seeds more cheaply than we are now doing lies in more effective weed control during seedbed preparation and in the handling of the field prior to that time.

The second phase of the weed problem, so far as it concerns commercial seed, is the avoidance of the contamination of clean fields by the distribution and planting of clean seed only. To this end the farmer must be given considerable help. It takes a lot of special training to make a seed analyst and the farmer is not a seed analyst. He cannot be expected to recognize most of the common weed seeds that may come in commercial seed. Last summer, on a weed control train conducted by the Michigan State College and the New York Central Railroad in southern Michigan, 130 farmers took part in a weed seed identification contest, in which they were asked to identify the seed of 15 common Michigan weeds, several of them important enough to be listed in the Michigan seed law as noxious weeds. Only one farmer was able to name all 15 weeds and his nearest rival made a score of only 80%. It was almost impossible to get any of the growers even to try to identify these weed seeds until a list of the 15 species was posted.

The results of this identification contest are given in Table 4.

TABLE 4.—*Results of Michigan weed seed identification contest.*

Number of contestants in group	Group score %
1	100
11	60–80
47	40–60
49	20–40
22	0–20

The protection of the grower against dangerous weeds lies not in his knowledge of weed seeds and his ability to spot them in commerical seed, but it lies in expert analysis and proper labeling of all farm seed.

It is, of course, much more dangerous to get some weed seeds in the field than others. Just which ones are most serious in this respect offers an excellent long-time problem, preferably for the United States Department of Agriculture. Dr. W. J. Beal began this study at the Michigan Station 50 years ago and Table 5 gives the results of germination after seeds had been buried 40 years. In the spring of 1930, the next lot of seeds will be dug up and tested and this experiment may continue for another 100 years.

Just what is a noxious weed? The state seed laws of some 30 states have attempted to define the term at least to the extent of listing those considered noxious and placing added restrictions on the distribution of seed in which these noxious weeds occur. The list varies from 1 in Alabama to 40 in North Dakota and includes 68 different species of primary and secondary noxious weeds for the United States, according to a report made to the Seed Council of North America by A. L. Stone of Wisconsin

For practical consideration that list looks too large. Probably no one is in better position to judge whether or not a weed should be classed as noxious than the agronomy workers in a given state. Certain it is that this list must vary for different sections of the country. Yet, have we anything more than opinion to guide us in this matter; opinion which is safe enough in the case of obviously bad or relatively harmless weeds, but which may need supporting evidence when it comes to those weeds the place of which is not so well defined?

Practically everyone agrees that certain restrictions should be placed on those weeds that are truly noxious. Certainly no grower wants unsuspectingly to buy a liberal supply of noxious weed seeds and scatter them over his fields. Right now there is something of a controversy before the Seed Council as to whether the labeling of noxious weeds on seed tags should show the number per ounce or the number per pound. .The resolution originally proposed by the legal representative of the seed trade was that the label show only the number of noxious weeds per gram, but in final form the resolution proposed that, "the Seed Council endorse the wisdom of the framers of the uniform seed law, in providing for the labeling of noxious weeds in commercial seed as to number per ounce rather than number per pound." That proposal was made a year ago last June, but action was delayed by the International Crop Improvement Association which contends that labeling of noxious weed seed content as to number per ounce tends to minimize the dangers of noxious weeds and make more salable seed which might contain such weed seeds in dangerous quantities. It further contended that farmers plant seed

TABLE 5.—*Beal's weed germination experiment.**

Weed	Year of test 5th	10th	15th	20th	25th	30th	35th	40th	Germination in 40th year
Amaranthus retroflexus (red root pig weed)	+	+	+	+	+	+	O	+	2
Ambrosia elation (rag-weed) . . .	O	O	O	O	O	O	O	+	4
Brassica Nigra (black mustard) .	O	+	+	+	+	+	+	+	18.9
Bromus secalinus (chess) . .	O	O	O	O	O	O	O	O	
Bursa bursa-pastoris (shepherds purse)	+	O	+	+	+	+	+	O	
Erechtites hieracifolia (fireweed)	O	O	O	O	O	O	O	O	
Euphorbia maculata (spotted spurge) .	O	O	O	O	O	O	O	O	
Lepidium virginicum (wild peppergrass).	+	+	+	+	+	+	+	+	2
Lychnis githago (corn cockle) .	O	O	O	O	O	O	O	O	
Anthemus cotula (mayweed-dog fennel)	+	+	+	O	+	O	?	O	
Malva rotundifolia (common mallow-cheeses)	+	O	O	+	O	O	O	O	
Oenothera biennis (common evening primrose)	+	+	+	+	+	+	O	+	38
Plantago major (broad-leaved plantain) .	O	O	+	O	O	O	O	+	10
Polygonum hydropiper (common smart weed)	O	+	+	+	+	possibly	O	O	
Portulaca oleracea (common purselane, pussley)	O	+	+	+	+	O	O	+	
Rumex crispus (curled dock)	+	?	+	+	+	+	+	+	18
Chaetochloa lutescens (foxtail?).	+	+	+	+	+	+	O	O	
Alsine media (common chickweed).......	+	+	+	+	+	+	O	O	
Trifolium repens (white clover). .	O	O	O	O	O	O	O	O	
Verbascum thapsus (common mullin)..	+	?	+	+	O	O	+	O	
Armaranthus graecizans (tumble weed). . .								+	66
Chenopodium album (lambs quarters). .								+	2 indivi

*Taken from report by H. T. Darlington, Amer. Jour. Bot., 9:266–269. 1922.

by the pound and when noxious weeds were labeled on that basis the true planting value of the seed could be quickly calculated.

At the last meeting of the Council this stand was supported by the official seed analysts, by representatives of the United States Department of Agriculture, and by the representatives of State Seed Commissioners and the Federated Seed Service, as well as by the International Crop Improvement Association.

Since the deliberations of the Seed Council are likely to be widely used when matters of seed legislation and seed policy are considered in the several states, the action which this Society takes and the final action which the Seed Council takes is of genuine importance.

THE USE OF SODIUM CHLORATE IN THE CONTROL OF JOHNSON GRASS[1]

HORACE J. HARPER[2]

Johnson grass is a serious pest in many places in the southern part of the United States, and although it can be controlled by heavy grazing and proper cultivation, there are many instances where such methods cannot be used effectively and where a chemical method for its control would be desirable.

During the past few years several investigations have been made in which sodium chlorate has been used as a means of controlling certain noxious weeds and recommendations have been made for the chemical eradication of quack grass (5),[3] bindweed (6), and Canada thistle (1). In order to determine whether or not sodium chlorate could be used alone or in combination with some other salt to control or eradicate Johnson grass, a series of experiments were planned to study the effect of rate, method, and time of application of the chlorate on the growth of the grass.

EXPERIMENTAL

This investigation was started in the spring of 1928 and the first application of sodium chlorate was made on May 15 on an area of Johnson grass which was making a very vigorous growth and was about 24 inches high. A solution of sodium chlorate containing 1 pound of chemical in each gallon of water was sprayed on the grass at the rate of 100 gallons per acre. Although a heavy rain occurred on May 16, 17, and 18, the leaves on the Johnson grass began to die near the tips. In one week the green color in the whole plant had disappeared, and the tops were killed. Studies on the roots and underground stems indicated that the effect of the spray had penetrated deep into the soil and that about 50% of the roots and the underground stems were dark brown or black in color. Many of the underground stems which were not killed, and also the secondary rootstocks which were beginning to form at the time the spray was applied, sent up culms later in the season, and strong vigorous plants developed over much of the area. A second spray was applied to these plants about August first. On October 10 an inspection of the area indicated three clumps of grass which had not been completely

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[1] Contribution from Department of Field Crops and Soils, Oklahoma A. & M. College, Stillwater, Okla. Received for publication November 16, 1929.

[2] Professor of Soils.

[3] Reference by number is to "Literature Cited," p. 422.

killed by previous treatment. These clumps were sprayed on that date and no grass appeared on this area during the season of 1929, indicating complete control.

On an adjoining area the Johnson grass was mowed just as the panicles were beginning to emerge from the sheath and the second growth was sprayed on July 28 when it was about 12 to 18 inches high. The rate of application was the same as in the previous experiment. Ninety-five percent of the plants were killed by the first spray and a second spray applied on October 10 destroyed the remainder of the plants. The Johnson grass on this area had gone to seed for several seasons, whereas on the area where the first test was made no grass had been allowed to go to seed, consequently during the season of 1929 entirely different results were secured. In the spring of 1929 a vigorous growth of Johnson grass appeared on the untreated area as indicated by the photograph shown in Fig. 1. On the adjacent area which had been sprayed only three plants developed from rootstocks. However, inspection from time to time revealed that a large number of young plants were starting from seed and by the middle of the summer a very good growth of Johnson grass was present on the land and it was necessary to spray this area again during the summer of 1929 to control the young Johnson grass plants since the area was not under cultivation. On areas which cannot be

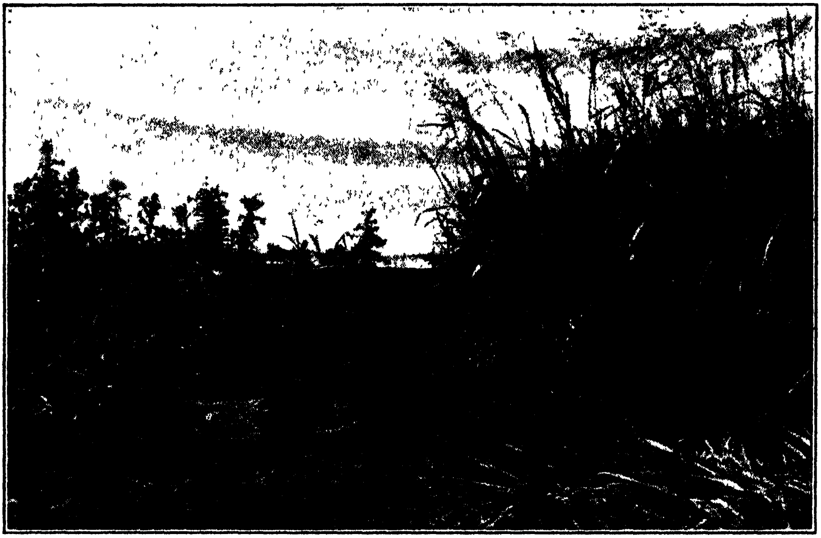

FIG. 1.—Showing the effect of two applications of sodium chlorate on an area of Johnson grass (left) and no treatment (right).

cultivated, Johnson grass should not be allowed to go to seed for at least two seasons before the spray is applied in order that the seed will be destroyed and another crop of Johnson grass will not form after the old grass has been destroyed by spraying.

Sodium chlorate was sprayed on another area of Johnson grass on October 10, 1928. The grass had been allowed to grow until late summer before it was cut, and a second growth about 20 inches high was present when the spray was applied. This treatment was not effective. No difference could be observed between treated and untreated areas in the spring of 1929.

In January 1929, calcium chlorate was applied at the rate of 200 pounds per acre on an area which had produced a vigorous growth of Johnson grass for several years. The chemical was scattered evenly over the ground which was moist from the melting of a light snowfall. Very little effect was produced on the growth of the Johnson grass in the spring and summer of 1929 Aslander (1) reports excellent results from a similar treatment of an area infested with Canada thistle. However, winter moisture conditions may be an important factor in the failure of the chlorate to kill the Johnson grass in this experiment. Very little rainfall or snow occurs in central Oklahoma during the winter months. In areas farther east where more winter rains occur, entirely different results might be secured.

In the spring of 1929 additional areas of Johnson grass were sprayed in order to check up on the experiments started in 1928. The results secured were very similar in regard to the use of the chlorate, except that where lighter applications of sodium chlorate were applied the plants were not killed, and after a short period of time complete recovery occurred.

Sulfuric acid has been recommended in controlling Johnson grass by Brown and Streets (2). In this investigation, however, it was found that a solution containing 10% of sulfuric acid would kill the leaves of the plants when sprayed on them, but did not poison the stems and new leaves would soon develop. Continual spraying with sulfuric acid might be effective, but on soils which are already acid this would be undesirable since the killing effect of sodium chlorate is superior and the expense of the two treatments are about equal.

In a recent editorial in *Industrial and Engineering Chemistry* (4), a severe criticism was directed toward agronomists who were recommending the use of sodium chlorate for the eradication of weeds. The basis of this criticism was the danger of fire which might occur when sodium chlorate was used by people who did not realize the dangers involved. Recently, there has been a chemical placed on the market and sold as calcium chlorate. The advantages which have been claimed for this compound as compared with sodium chlorate are that it is hygroscopic and does not dry out as quickly under conditions of low humidity and also that there is less danger from fire, both of which are true. However, a careful analysis of three samples of this weed killer revealed the following results which were calculated from determinations made on the calcium, sodium, chloride, and chlorate content of the sample. The moisture content was secured by subtracting the total amount of the different elements from 100. The data are as follows:

	Sample I	Sample II	Sample III
Sodium chlorate	49.75%	62.27%	57.07%
Sodium chloride	3.53%	———	1.50%
Calcium chloride	34.22%	32.14%	34.43%
Moisture	12.40%	5.59%	7.00%

In experiments conducted at the Oklahoma Agricultural Experiment Station, it has been found that a mixture of 85% of sodium chlorate and 15% of neutral calcium chloride will soon become a paste if exposed to the atmosphere and when a solution of this material is allowed to dry on a piece of wood it is quite difficult to burn the wood unless it is held in a free flame. Further experiments indicate that 15% of calcium chloride will not allow the sodium chlorate to powder on the leaves of plants and dust off in dry weather. No advantage occurred in favor of the sodium chlorate-calcium chloride mixture over sodium chlorate used alone when sprayed on an area of Johnson grass this past season, even though the sodium chlorate formed a powder on the surface of the leaves soon after it was applied. It required about three or four days for the sodium chlorate-calcium chloride mixture to be absorbed. The cost of calcium chloride is considerably less than that of sodium chlorate, consequently, the cost of the commercial weed killers made from the mixture should not be higher than that of sodium chlorate. In fact, where the percentage of calcium chloride in the sample is high, the cost should be considerably less per pound because it will be necessary to use more chemical per acre to secure the same results which would be produced by an application of 100 pounds of sodium chlorate.

Studies on the utilization of soap as a spreader in the sodium chlorate solution in order to increase its effectiveness did not indicate that the soap had any value.

TOXIC EFFECT OF CHLORATE ON SOILS

Latshaw and Zahnley (7) state that sodium chlorate has little or no effect on the following crops. During the past season at the

Oklahoma Experiment Station on areas which were sprayed twice with sodium chlorate in the summer and fall of 1928, a considerable decrease in the yield of oats occurred. The toxic effect produced is shown in Fig. 2. The cause of this condition has not been definitely determined. Studies on the rate of decomposition of sodium chlorate when applied to the soil indicated that the chlorate was completely decomposed in a week's time under favorable moisture conditions and summer temperature, consequently the effect could hardly be due to the sodium chlorate since several months elapsed between the time the last spray was applied and when the oats were planted. Data on nitrification indicate that sodium chlorate retards the nitrification of compounds of organic and inorganic nitrogen when these substances are added to the soil. Further studies are being made on this phase of the investigation and indications at present point to certain oxidation products produced by the sodium chlorate as the probable cause of this condition. Further studies on soils of varying reaction are also being made which will be published in another paper.

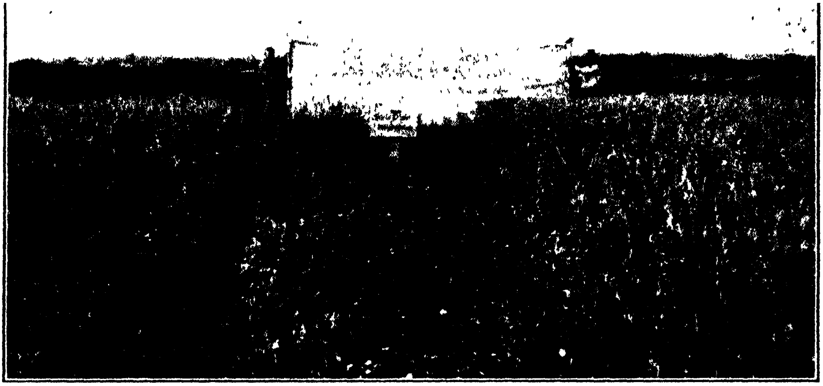

FIG. 2.—Showing the toxic effect of 200 pounds of sodium chlorate applied in two sprays in the summer and fall of 1928. Left, oats on area which was sprayed; right, oats growing on untreated area.

SUMMARY

A study was made in order to determine the effect of the time, rate, and method of application of sodium chlorate and certain other materials in controlling Johnson grass, a serious pest in certain areas of the southern part of the United States.

It was found that two or three sprays would eradicate the grass. If viable seed were present in the soil, however, a new crop of plants

would appear the following season, and unless the area was under cultivation another spray would be required to kill the young plants.

Where the Johnson grass can be cut with a mower, the first crop should be cut just as the heads begin to appear and the spray should be applied to the second growth when it is about 12 to 18 inches high. The rate of application should be at least 100 gallons per acre and each gallon of solution should contain 1 pound of sodium chlorate.

Sulfuric acid did not give as good results as sodium chlorate in the control of Johnson grass

Sodium chlorate sprayed on the plants in the fall or scattered on the soil in the winter was not effective.

A study of the composition of a commercial weed killer, which was supposed to be calcium chlorate, was made. The analyses indicated that it was a mixture of sodium chlorate and calcium chloride.

A marked toxic effect was produced this past season on a crop of oats grown on land which had received 200 pounds of sodium chlorate applied as two separate sprays in the summer and fall of 1928.

Soils treated with sodium chlorate have a lower nitrifying power than untreated soils. This may only partially explain the toxic effect of the chlorate because it was found that the chlorate was decomposed in a moist soil at a summer temperature in less than seven days, but that the nitrifying power of the soil is considerably depressed for several weeks following the treatment.

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CONTROLLING PERENNIAL WEEDS WITH CHLORATES[1]

H. W. Hulbert, J. D. Remsberg, and H. L. Spence[2]

Considerable attention has been directed during recent years toward the control of perennial weeds through the use of chemical herbicides. The herbicide sought is one which is non-poisonous to animals, of greatest ease of application, and most effective in the control of the various species at minimum expense, without permanent injury to the soil.

Latshaw and Zahnley (1)[3] reviewed the efforts directed toward the control of field bindweed (*Convolvulus arvensis*) by means of various chemicals. Sodium chlorate applied as a spray following the full bloom period gave most promising results. In a subsequent report, they (2) suggested the use of magnesium and calcium chlorates as substitutes for sodium chlorate since these do not present the fire hazard encountered through the use of the latter.

Hansen (3) reported that heavy applications of sodium chlorate produced satisfactory results when sprinkled in water solution over mowed areas of quack grass A plat which received the chemical at the rate of 13 6 pounds per square rod showed some recovery the following year. Two plats which received 27.2 pounds and 54.4 pounds per square rod, respectively, were completely free from the weed. In a subsequent publication, he (4) reported sodium chlorate effective on perennial weeds in Indiana when three successive applications of 1½ pounds each per square rod were made

Sodium chlorate as an herbicide first received attention in Idaho during the season of 1927. Numerous applications were made to determine its value for weed control purposes. The results of these preliminary applications were gratifying, and in consequence, more elaborate investigations were conducted during 1928. Cooperating with county agents, experimental plats were located in different sections of the state in order to cover the various conditions under which the more serious weed pests are found. Treatments were made at intervals during the season to determine the stage of growth at which the plant was more susceptible to the action of the herbicide.

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[1] Contribution from the Department of Agronomy, Idaho Agricultural Experiment Station, Moscow, Idaho. Presented at the annual meeting of the Society held in Chicago, Ill., November 15, 1929. Published with the approval of the Director as technical paper No. 64.

[2] Agronomist, Extension Agronomist, and Assistant Extension Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 433.

Chlorates of calcium[4] and magnesium[5] received attention during the latter part of the season and were used comparatively with sodium chlorate. The fire hazard encountered through the use of sodium chlorate resulted in several very serious accidents, and it was hoped that by the use of deliquescent salts, such as calcium and magnesium chlorates, this hazard might be minimized.

Thirteen species of perennial weeds were treated under irrigated, non-irrigated, and dry land conditions, as follows: Morning glory (*Convolvulus arvensis* and *C. sepium*), Canada thistle (*Carduus arvensis* and *C. arvensis* va. Linn.), Russian knapweed (*Centaurea picris*), white top (*Lepidium draba*), perennial sow thistle (*Sonchus arvensis*), quack grass (*Agropyron repens*), blue-flowering lettuce (*Lactuca pulchella*), poverty weed (*Iva axillaris*), yellow toadflax (*Linaria vulgaris*), willows (*Salix* sp.), and wild rose (*Rosa* sp.).

A resume of observations made on treated areas of the above species to July 8, 1920, was presented in a paper before the annual meeting of the Western division of the American Society of Agronomy at Moscow, Idaho, on July 17, 1920. This paper contains all of the information included in that report, together with generalized statements concerning the findings of observations made since that time. The summary treats indiscriminately with both commercial and experimental applications. Preponderance of applications made at the rate of 3 pounds per square rod is due to the fact that preliminary investigations conducted in 1927 indicated that this was the minimum amount required to produce satisfactory results.

RESULTS UNDER IRRIGATION

MORNING GLORY[6]

Seven observations on treatments of 2 pounds or less per square rod showed only one complete kill. Plants recovering showed damage and recovery was questionable. Nine observations on applications of 2½ pounds showed three with complete kill, five with slight recovery but with plants badly damaged, and one with full recovery due to the burning of foliage three days after spraying. Three observations on 3-pound applications, applied in 1-pound lots at three intervals during the growing season, showed complete control.

Observations were made on 130 plats on which sodium chlorate was applied at the rate of 3 pounds per square rod at one application. Of these, 97 showed complete control of plants recovered.

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[4] Atlacide secured from Chipman Chemical Engineering Co., Boundbrook, N. J.

[5] A commercial product from the Dow Chemical Co., Midland, Mich.

[6] *Convolvulus arvensis* unless otherwise noted.

Failure to extend spraying to outer edges and ununiform application were obvious on several areas, but these features could not be attributed to lack of effectiveness of the chemical. The failures are classified as to probable cause as follows: 3 were burned before fall, 4 were irrigated shortly before treatment, 2 were irrigated shortly after treatment, 1 was cultivated shortly after treatment, 9 were on ditch banks near water's edge, 2 were under water for a long period early in the spring, 3 because of rubbish on area, and 7 were unexplained.

It is significant to note that of the 97 applications many were made after grain had been harvested, after two or three crops of hay had been cut, after snowfall, and on areas which had been pastured.

Seventeen observations were made on areas treated with 3½ pounds or more. The effectiveness of heavier applications was found to depend upon thorough coverage and upon treatment of areas previous and subsequent to the time of applications

Two observations were made on applications of 3 pounds to *C. sepium*. One gave complete control, while the other gave only about 90% control The partial kill might be attributed to the fact that the area was sub-irrigated.

Twelve observations were made on areas of *C. arvensis* treated with calcium and magnesium chlorates in equivalent amounts to sodium chlorate. In every case results were closely comparable, except that magnesium chlorate appeared slightly more effective on a dry-weight basis. Three observations on areas treated with calcium chlorate dust showed results equivalent to areas sprayed with equal amounts of the chemical in water solution

Observations made during the latter part of the current season on many of the patches included in the above summary, together with many additional 1928 treatments on this species, have indicated that the areas on which growth recurred in 1929 needed only very light applications to complete control. The plants which survived were so weakened by the application that they were easily controlled by a second light application.

It is apparent that irrigation before the plants are entirely eradicated reduces the effectiveness of the treatment. There is also indication that late summer and fall applications are more effective than spring or mid-summer applications. In several instances, seedling plants were found on patches treated late in the summer, a feature which would seem to complicate the problem of eradication. Ordinary light cultivation practices were sufficient to prevent reinfestation by seed which matured before the area was treated.

CANADA THISTLE

Observations were made on 104 applications varying from 1½ pounds to 9 pounds of sodium chlorate per square rod. Two areas which received 2 pounds each showed complete control, while 12 failed, but the few plants which returned showed damage. Five areas treated with 2½ pounds each were freed from the pest, while 17 produced sickly plants. Twenty-nine of 56 areas treated with 3 pounds per square rod showed complete control The remainder developed sickly plants, many of which died with the advent of hot weather.

It is significant to note that 12 of the failures occurred in Albion Valley, a section of Cassia County, where various unfavorable conditions occur, such as high water table due to sub-irrigation and heavy vegetation other than thistles. One 5-acre patch treated at the rate of 3 pounds per square rod gave complete control except where a horse had been buried five years before. Three areas treated with 3 pounds per square rod and followed with another application of about 1 pound late in the season gave complete control. Four areas received two applications of 3 pounds each without complete control, with the cause undetermined. The areas treated with dry sodium chlorate at the rates of 7 and 9 pounds showed complete control.

A distinct species or sub-species of Canada thistle, variously termed, was located and treated. Seventeen observations were made on applications varying in quantity from 2 to 7 pounds per square rod, and none produced complete control. Five observations on calcium chlorate used comparatively with sodium chlorate produced similar results. Dusting the calcium salt was no more or no less effective than the wet treatment on two comparative tests.

Observations made late in 1929 showed that results with Canada thistle are not fully as satisfactory as with the morning glory. It was noted that very few of the treated areas of this pest were completely eliminated by a single application. New plants were found to develop late in the growing season, and these required subsequent treatment. The plants, however, were very sickly and very scattering. The principal difficulty in treating Canada thistle is the elimination of recurring plants which may appear continuously during the growing season of the year following first treatment. This would indicate that continued attention to areas of Canada thistle treated with chlorates is necessary to effect complete eradication.

RUSSIAN KNAPWEED

This pest is peculiarly adapted to effective control by spraying possibly because of the fibrous nature of the large, dark-colored root stalks. Sixteen observations were made on areas treated with sodium chlorate at rates of 2 pounds or less per square rod. Only one of these, treated with two applications of 1 pound each, gave complete control. Four observations on 2½-pound applications showed three which would require a follow-up application the next year. The kill was approximately 90%. One plat had been plowed late in the fall and the treatment was a complete failure.

Forty-six plats received 3-pound applications and 21 showed complete kill on the area covered. Seven partial failures were attributed to disturbance of the plats just before or soon after treatment. One of these had been traversed frequently by a wagon about two weeks before treatment. The wagon tracks were plainly visible through the recurring vegetation The remaining 18 showed scattering plants on the way toward recovery which would indicate that follow-up applications were necessary. Twelve areas which received more than 3 pounds either as single or repeated applications showed complete kill, except two One of these areas was burned after treatment and the other was used as hog pasture before and after treatment. Two applications of calcium and sodium chlorates used comparatively showed equal killing ability on this weed.

Observations late in the summer of 1929 on areas treated in 1928 showed that Russian knapweed may be effectively controlled with lighter applications than are required for morning glory or Canada thistle. It is particularly essential that the edges of knapweed patches be watched closely the following season. This pest quite frequently has root stalks which extend beyond the outermost limit of top growth. Chlorates cause rapid disintergation of the roots of the Russian knapweed. However, it is found that adventitious buds form on apparently dead roots, and the weed may become re-established. Three instances were observed where light cultivation during June, following an application made in 1928, was fully successful, the budding plants being effectively controlled before they had a chance to re-establish themselves.

WHITE TOP OR HOARY CRESS

In southern Idaho no single applications of less than 4 pounds per square rod gave complete control, though applications of 1½ pounds appeared as effective as 3½-pound applications. One complete kill at 4 pounds was noted in six observations at that rate.

Three complete kills were observed where 4½ pounds had been used, while three other areas of similar treatment gave about 80% control. Two applications of 3 pounds each gave complete control on one area. Three comparative tests using calcium and sodium chlorates indicated that the calcium was slightly more active than the sodium.

White top is apparently one of the most difficult plants to control by the use of chlorates. Every available opportunity was used to observe areas treated last season. In general, the findings may be summarized as follows: White top under irrigation cannot be effectively controlled with a single application unless excessively heavy amounts are applied. The most economical and thorough practice is that of spraying the plants just in time to prevent the maturing of seed. This treatment will greatly retard development. However, the plants will recover to such an extent that the vitality will seem to be unimpaired. A second application should be made shortly after the recurring plants come into bloom. The second application is ordinarily effective in making a complete kill. There have been only 3 instances out of 25 observed where a third application was required. The amount of material to use in each application need not be more than a sufficient quantity of a 12½% solution (1 pound to 1 gallon) to cover all vegetation thoroughly. On average patches this does not amount to more than about 1 to 2 pounds per square rod with each application.

PERENNIAL SOW THISTLE

Nine areas received amounts varying from 2 to 7 pounds per square rod, and none were completely successful. One area treated with 6 pounds per square rod showed about 90% kill and various areas receiving 3 pounds appeared nearly as satisfactory. Further work is under way using both calcium and sodium chlorates in varying amounts, methods, and times of application. As yet no conclusive information has been obtained.

Late 1929 summer observations made on areas treated during the season of 1928 showed that perennial sow thistle is more easily controlled than was indicated upon earlier observations. This plant produces a very heavy root system with large fleshy rootstalks, which when treated, continue to send out adventitious buds. These buds reach the surface and produce very sickly sprouts which tend to disappear during the warm, dry weather. It would seem that the most effective time to make application to the sow thistle was late in the spring and while the leaves were in a "rosette" condition. Applications made during the active growing season are not fully effective. On the other hand, some of the best results were obtained on areas treated after the plants had fully matured and when the top growth was practically dead.

If applications are made during the "rosette" period, considerable difficulty is encountered in making the spray material adhere to the glossy leaves. It has been found that with the use of a heavy roller, the leaves may be flattened upon the ground and slightly bruised and if sprayed immediately will retain a sufficient amount of solution to be effective. As the plant approaches maturity, the solution tends to cling to the leaves more satisfactorily. Only in rare cases and in certain spots was complete control obtained with a single application. It appears that repeated applications of from 2 to 4 pounds per square rod will be required. The results of the investigation conducted during the 1929 season are not available, since it has been found that complete kill did not occur until after the winter season.

QUACK GRASS

Five areas of this weed were treated with sodium chlorate Two areas with 2-pound applications showed one completely successful and one only partially so. The latter indicated that the rate of application was too light, since scattering plants recovered. Three areas treated with 3 pounds per square rod each during late fall showed 100% control. Very few late observations on the use of chlorates on quack grass areas were made With few exceptions, the areas treated in 1928 were placed under cultivation. Only one instance was reported in 1929 of live plants found on plats treated in 1928.

There is one instance of interest where a farmer had cultivated a patch of quack grass for several seasons without success. During the current season the patch was not cultivated, but was sprayed late in June. The farmer felt confident that the plants were killed and plowed the field in August. Recent observation showed that comparatively few of the plants will return. The roots appear to be fleshy and crisp, but are not producing new growth. Whether growth will occur depends upon action of the chemical during the ensuing winter.

BLUE-FLOWERING LETTUCE

The evidence toward the reaction of herbicides on this pest is not sufficient to warrant a definite statement. Seven plats treated in 1928 were visited in the spring of 1929. At the time of this observation all but one, a 6-pound application, would require a second treatment. The remainder were 3-pound plats and showed about 80%

kill. Late 1929 summer observations made on the same 1928 applications mentioned above showed that the blue-flowering lettuce reacts to chlorates quite similarly to the perennial sow thistle. This pest has a glossy leaf and may be most effectively treated following rolling, or as the plant approaches maturity. It appears also that repeated applications will be required, as comparatively few complete kills were obtained from single applications.

WILLOWS

A 3-pound application of sodium chlorate per square rod, using particular care to cover the willow plants, gave satisfactory control.

RESULTS IN NON-IRRIGATED AND DRY-FARM AREAS

Under irrigation 3 pounds of chlorate per square rod is necessary for eradication of most perennial weeds. In non-irrigated and dry-farm areas complete control is effected with lighter applications, 2 pounds of chlorate per square rod usually being sufficient for eradication. Morning glory, quack grass, Russian knapweed, and Canada thistle were eradicated by spraying with a 10% solution (4 pounds of chlorate to 5 gallons of water) in sufficient amount to cover the weeds thoroughly. This practice requires approximately 2 pounds of chemical per square rod under average conditions.

Yellow toad flax was completely eradicated by the application of 2 pounds of sodium chlorate per square rod. A 3-pound application produced no more effective control, while a 1-pound application gave only a 50% kill. Canada thistle on reclaimed river bottom land, with the water table within 3 to 4 feet of the surface, required between 3 and 4 pounds of sodium chlorate per square rod for complete control. Similar amounts of chlorate seem to be necessary for all perennial weeds where high water tables prevail. White top or hoary cress required similar amounts of chlorate for eradication. Best results were secured by repeated light applications, with the first treatment applied during full bloom. The other applications should follow as soon as new growth attains sufficient size.

Late applications of calcium and sodium chlorate gave equally good results on morning glory. The 1929 applications of calcium applied in spray and powdered form appeared to be satisfactory. Final results cannot be obtained until the 1930 season.

Effectiveness of chlorate treatment is greatly lessened if treated areas are disturbed in any way before the following spring. Areas burned or cultivated after treatment produced heavy reoccurring infestations the following season. Areas disturbed by cultivation previous to treatment cannot be effectively controlled by one application. In one instance a 90% kill of Russian knapweed was secured after the treated areas were late fall plowed about two months after treatment. Calcium chlorate applied in powdered form completed the eradication. The powder was applied when the new growth was about 10 inches high.

Late applications of chlorates have proved most effective. Weed areas sprayed after September 1 made no second growth. Applications made at blooming time prevented the formation of seed, but sometimes the reoccurring growth requires another application later the same season to complete eradication. A 7-acre field of morning glory pastured through late summer was almost completely eradicated by a September application of sodium chlorate. Approximately 1,000 pounds of chlorate were required for the work. A light follow up spraying completed eradication.

Strength of the spray solution had no effect upon the completeness of eradication of morning glory. Seven and one-half, 10, and 12½% solutions were equally effective when equal weights of the chemical were applied per unit area.

Spraying weed infested areas after removal of grain crops has proved satisfactory. This method is especially effective if the grain crop was fall-seeded. Under such conditions the weeds had apparently become well established and in suitable condition for eradication Complete control of morning glory, Canada thistle, and Russian knapweed were secured after harvesting winter wheat. Using this method, weeds can be eradicated without the loss of a crop year. If follow-up work is necessary it can be done after the next crop harvest.

EFFECT OF CHLORATES ON SUBSEQUENT CROPS

A 1927 application of 15 pounds of sodium chlorate per square rod immediately surrounding a prune tree did not prove fatal under irrigation. However, in 1928 the leaves turned yellow and the fruit dropped before maturity. In 1929 the tree appeared normal. In irrigated sections, grain crops seeded the spring following chlorate treatments turn yellow. The first application of water usually restores them to apparently normal condition. In rainfall areas, treated patches sometimes show the effect of the chlorate treatment throughout the subsequent season. Field peas and cereals yellow and die. Light showers during the growing season hastened their death. Such damage is apparent only in seasons when winter precipitation was not sufficient to wash the chlorate from the soil. There is no permanent damage to the soil by the application of chlorates in the amounts recommended in Idaho.

SUMMARY

The commercial use of chlorates for weed control purposes in Idaho has met with gratifying success. There are certain features which limit the effectiveness of the treatments. These may be summarized in a general way from extensive observations made during the entire growing season. It has become very apparent that the full effectiveness of the treatments is not evident until the following season. It is not uncommon for the plants to continue to grow after the applications, only to disappear entirely after the winter season. In order that best results be obtained, the areas should not be cultivated just prior to the application of chlorates. The under-ground root system should be represented by an appropriate amount of top growth

The effectiveness of the treatments increases as the plant approaches maturity. This possibly may be attributed to the fibrous nature of the plant nearing maturity and the ease of dissemination of the chemical through the root system The borders of the treated areas should be watched closely the following season, since it is apparent that the underground root system extends beyond the outer limit of the top growth. Areas should not be irrigated following treatment This apparently results in dissemination of the chemical through the soil moisture and subsequent leaching from the soil.

In instances where the water table approaches the surface of the ground at certain seasons of the year, it has been noted that treatments are more effective if the water table remains stationary at the time of application or is slowly lowering. In case the water table is continually approaching the surface of the ground, there is a zone of roots near that water table which will not be effectively killed. The temperature of the air and the time of the day during which the application is made appear to have very little influence upon the effectiveness.

Complete eradication does not follow with sufficient frequency to warrant the statement that a single application is sufficient. Experience has shown that it is much better to inform the farmer that he should not expect complete control with a single application and have him pleased if no further work is necessary, than it is to inform him that complete control may be expected and have him disappointed if further work is required.

Under irrigation, it would seem that the following general recommendations might be made: Dissolve the chemical in water at the rate of 1 pound per gallon. Apply to plants in undisturbed areas after full bloom stage and in sufficient quantity to moisten all vegetation. Leave the area undisturbed through the remainder of the season, except in the case of white top where a second application may be required to prevent seeding. Repeat the application the following season, if necessary.

In non-irrigated areas, the general recommendation for all perennial weeds is to apply a 10% solution in sufficient amount to wet the weeds thoroughly.

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THE EFFECT OF SODIUM NITRATE ON THE COMPOSITION OF THE EXPRESSED SAP OF THE SMALL GRAINS[1]

M. M. McCool and M. D. Weldon[2]

According to our investigations, the application of sodium nitrate to the soil as fertilizer causes changes in the mineral content of the cell sap of the crops growing thereon. These changes may be produced as a result of the action of the fertilizer within the soil, making the plant nutrients either more or less available as the case may be, or as a result of their effect on the growth and activity of the plant in absorbing and utilizing the nutrients. It was indicated in a previous paper (3)[3] that if the application of a nutrient as fertilizer causes a decided increase in plant growth, the percentage of other nutrients in the plant sap usually is decreased. In some cases, however, the application of an element in the form of fertilizer may result in an increased availability of some other element, which may therefore be present in a larger proportion in the plant sap It appears that if these two factors work against each other, the nutrients concerned may fluctuate upward or downward as one factor or the other dominates the situation.

EXPERIMENTAL RESULTS

The crops used in obtaining the data presented in this paper were barley, oats, rye, and wheat. They were grown in field plats receiving Chilean nitrate of sodium at three different rates, namely, 50, 100, and 150 pounds per acre. Check plats receiving no nitrate were included in each set. Samples were taken at intervals during the spring and summer. Each crop was grown on two soil types, namely, Miami loam and Hillsdale sandy loam.

The Miami loam has a surface layer of light brown loam, usually fairly well supplied with organic matter. Below this is a slightly leached layer of grayish material, somewhat more sandy and friable than the surface. The B horizon consists of reddish brown or yellowish brown, compact, coarsely granular clay loam which extends to a depth of 36 to 40 inches. The A horizon and the upper part of the B horizon are usually somewhat acid in reaction, while the lower part of the B horizon is usually calcareous. The parent material is massive, calcareous, glacial till. The fertility of the soil is medium to high.

[1] Contribution from Soils Department, Michigan State College, East Lansing, Mich. Journal Article No. 23 (N. S.). Received for publication November 16, 1929.

[2] Professor of Soils and Research Assistant in Soils, respectively.

[3] Reference by number is to "Literature Cited," p. 437.

The Hillsdale sandy loam is somewhat lighter in texture and color than the Miami loam, and lower in organic content. The B horizon is a yellow or yellowish brown material which contains a considerable amount of colloidal material, but it is sandy and friable. The soil is strongly acid at the surface and may exhibit some acidity to a depth of 4 feet. The unweathered parent material is somewhat calcareous. The fertility of the soil is moderate, being usually a little lower than that of the Miami loam.

Each soil type has fairly good natural drainage and responds well to applications of lime and fertilizers.

The methods used in obtaining and analyzing the plant sap have been described in a previous paper (3).

The graphs in Fig. 1 indicate that, when varying amounts of nitrate of sodium were applied as fertilizer, the phosphorus content of the plant sap was usually decreased by the 50-pound amount; that the 100-pound application caused a further decrease in some cases and an increase in others; and that the 150-pound application usually produced a rise above the lowest level, and in some cases, a rise above that of the check.

The phosphorus content of the sap showed a general tendency to increase with the age of the crop. In the wheat on Miami soil, which was sampled three times, the lowest phosphorus levels were reached at the second sampling on June 8 and the highest at the third sampling on June 28. This makes it seem probable that in the cases of wheat and rye on Hillsdale soil, later samplings would have shown higher phosphorus levels, since the last samplings obtained were much earlier than the last samplings in the other cases. These two were the only cases in which the last sampling was not highest in phosphorus. It may be concluded, therefore, that the phosphorus content of the sap of the small grains tends to increase during the latter part of the growth period.

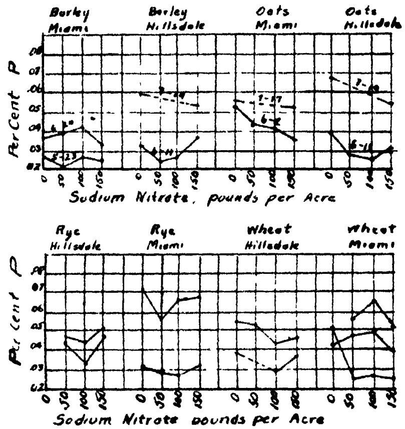

FIG. 1.

The potassium content of the sap of the small grains, indicated by the graphs in Fig. 2, was inclined to be lower in the later samplings. The 150-pound application of sodium nitrate usually decreased the potassium content, while the effects of the smaller applications were quite variable.

The use of sodium nitrate generally reduced the calcium content of the sap, as shown in Fig. 3. The decrease in calcium content was generally greater with the greater applications of nitrate. This effect may be due to a number of factors. The sodium ion may render the membranes of the root hairs less permeable to the calcium ion. Similar phenomena have been discussed by Crist (1), MacDougal, (2), and others. In a few instances, principally in the case of the 50-pound application of nitrate to rye on Miami soil, the calcium content was greater on the fertilized than on the check plat. This discrepancy apparently was due to a variation of the soil on the plat in question. The results obtained on other fields were quite consistent.

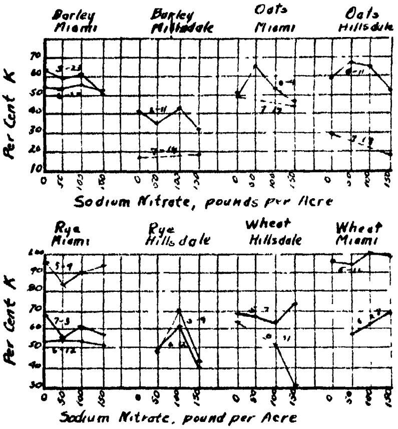

FIG. 2.

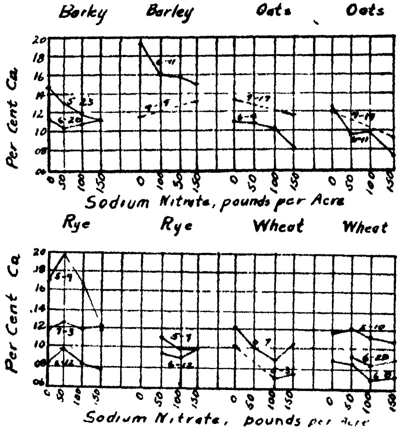

FIG. 3.

The calcium content showed a general tendency to decrease with the age of the crops until near maturity, at which time an increase usually occurred. In the June samplings the calcium levels were in every case lower than in the May samplings, while they were higher in July or late June samplings than in early June samples in four cases out of five.

The magnesium content of the sap was not greatly influenced by the nitrate applications (Fig. 4). It showed a general tendency to fall as the amount of nitrate was increased to 100 pounds per acre. The 150-pound application, however, usually caused a rise. The later samplings generally contained more magnesium than the earlier ones. The content of magnesium appeared to fluctuate less as a result of the nitrate treatments than that of the other elements. The variations during the season were also smaller.

The fluctuations in phosphorus content seemed to indicate that the nitrate influenced the availability of phosphorus in the soil. In order to determine, if possible, whether or not this was true, several series of extractions were made, using Hillsdale sandy loam and Miami loam surface soils with nitrate treatments up to 250 pounds per 2,000,000 pounds of soil in 50-pound increments. The extracts were obtained by the collodion sack method described by Pierre and Parker (4). However, the phosphorus contents of the extracts of soils receiving up to 300 pounds per 2,000,000 of superphosphate containing 44% phosphoric anhydride and varying amounts of nitrate were so small that they could not be determined by the usual colorimetric method. None of the extracts contained more than 0.06 p.p.m. of phosphorus. For this reason no effect of sodium nitrate on the solubility of phosphorus in the soil could be demonstrated.

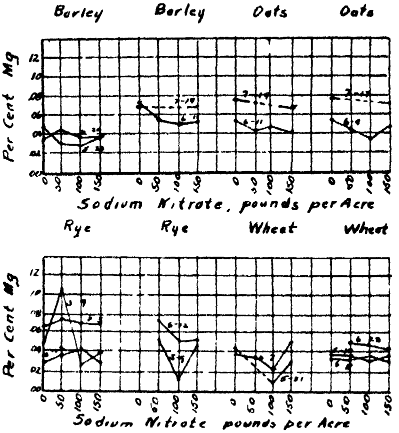

FIG. 4.

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2. MACDOUGAL, D. T. Permeability and the increase of volume of contents of living and artificial cells. Proc. Amer. Philos. Soc., 62:1–25. 1923.
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4. PIERRE, W. H., and PARKER, F. W. The use of collodion sacks in obtaining clear soil extracts for the determination of the water-soluble constituents. Soil Science, 23:13–32. 1927.

A NEW METHOD OF MEASURING THE COMPARATIVE RATE OF PERCOLATION OF WATER IN DIFFERENT SOILS[1]

George John Bouyoucos[2]

There is probably no other field in soil physics which is so devoid of reliable laboratory methods as that of percolation of water in soils. Indeed, it can probably safely be said that there is no method for studying the rate of percolation of water in soils which can be regarded reliable for comparative purposes. These statements are self-evident when it is considered that the results yielded by the present methods may vary in duplicate experiments from 100 to 1,000% without apparent reason, and when every attempt is made to perform the duplicate experiments in an identical manner. Furthermore, even if the duplicate results agree, they may not be really true for the different soils.

Possibly there may never be worked out a laboratory percolation method for soils that will be absolutely satisfactory, due to the fact that the factors that come into play are so numerous and of such variable nature and are so exceedingly difficult to control.

In the present paper there is presented a new method which would seem to possess many advantages over the old method and which appears to give quite satisfactory results.

DESCRIPTION OF METHOD

The principle of the method consists of allowing a soil to slake in an excess of water into its ultimate natural structure, stirring the soil mass gently in the excess of water, then applying suction and measuring the rate of flow of water.

The main apparatus necessary, or the one used in this method, is shown in Fig. 1. It consists of a Büchner funnel of about 8 cm in diameter and 4 cm deep, a 500-cc graduated cylinder, and a rubber stopper with two holes, one for the funnel and one for the bent glass tube which connects to the faucet. The upper end of the cylinder containing the lip is cut off and adhesive tape is wound around the mouth to prevent it from breaking when the rubber stopper is pushed in.

The detailed procedure consists of placing a hard filter paper (No. 50) on the bottom of the funnel and immersing both in a 1,000-cc beaker filled with tap water. After the filter paper becomes soaked

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[1] Contribution from Soils Section, Michigan State College, East Lansing, Mich. Received for publication November 18, 1929.

[2] Research Professor in Soils.

and adjusted in its proper position, 100 grams of dry natural soil, or soil dried in lumps, is poured into the funnel. The soil then immediately begins to slake into particles or aggregates which are considered to represent the ultimate natural structure of the soil.[3]

The soil is allowed to stand about two hours in water so that it slakes completely and becomes thoroughly soaked, the funnel is taken out of the beaker of water and inserted in the rubber stopper on the graduated cylinder. Meanwhile, care is taken that the funnel is kept filled with water. Then, while the funnel is almost filled with water, the soil is gently stirred. An excellent stirrer is the handle of a small horn spoon The handle is flat, about 1 cm in width, and slightly curved up at the end, all these conditions tending to make it an ideal stirrer for this purpose. The stirring is best done by gently pushing the end of the handle into the bottom of the soil and then gently lifting it up. Great care is taken not to stir the soil too much because then the soil is dispersed and thus the purpose defeated. Lifting up the stirrer about 15 times around the soil mass is quite sufficient to help break down any small lumps that were prevented from slaking and to bring about an approximately uniform soil particle arrangement or compactness.

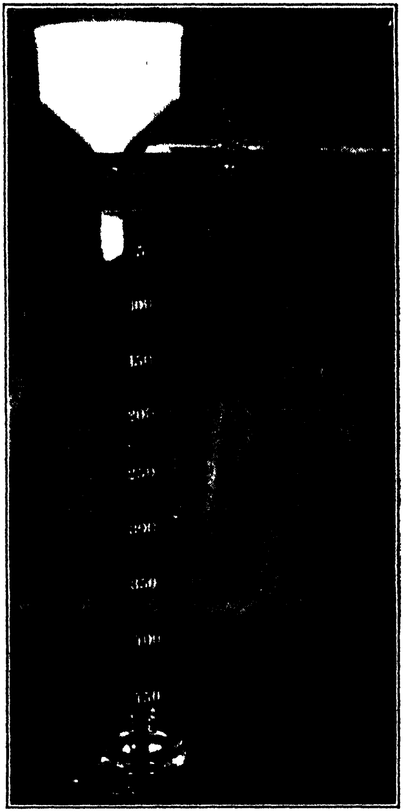

FIG. 1.—Apparatus used for measuring the comparative rate of percolation of water in soils.

The funnel, together with the rubber stopper, is then pulled out of the cylinder and the latter is thoroughly emptied of water. The rubber stopper with the funnel attached is put back on the cylinder and connected to the suction pump. After seeing to it that the funnel is full with water, the vacuum is applied, which starts the flow of water through the soil. In order that the soil system may become settled and more or less in equilibrium, the suction is continued for about 30 minutes, or longer, before measurements are commenced on the rate of flow of water. Meanwhile, a layer ofwater isalways kept above the soil column. As a matter of fact, the soil should never be allowed to drain completely, a layer of water always being kept above it. If it is allowed to drain completely even for half a minute, the system is changed and consequently the rate of flow is also changed. It is easy to see why the system changes when the soil is allowed to drain completely, because the soil layer cracks, becomes more compacted, the particles rearrange themselves, etc. Hence, one has to follow a standardized procedure in order to get constant and truly comparable results.

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[3] BOUYOUCOS, G. J. Effect of temperature on some of the most important physical processes in soils. Mich. Agr. Exp. Sta. Tech. Bul. 22. 1915.

In adding water to the soil, one must be very careful not to add it with force because then the stream makes a hole in the soil and disturbs the system. The best way to add the water is to hold a spoon close to the surface of the soil, and allow the stream of water to fall upon it. In this way the force of the stream is reduced to a minimum.

After the water has run through the soil under suction for half an hour or more, the soil column thus becoming more completely settled and more in equilibrium, the funnel, and the stopper are detached carefully from the cylinder and the latter emptied of its water Then the attachment is again made and the measurement of the flow of water is commenced.

The plan adopted for measuring the rate of flow is to obtain the length of time necessary for a definite quantity of water to pass through the soil layer. For more accurate average results it is advisable to use a large volume of water. In the present work 400 cc were adopted as a standard. The measurement of time is commenced after the suction is turned on and the water begins to flow into the cylinder.

After a definite volume of water has passed through the soil, the suction is disconnected from the soil by disconnecting the tube attached to the faucet from the glass tube on the rubber stopper (Fig. 1). The stopper is then carefully pulled out of the cylinder and the water poured off the latter. If the results are to be repeated on the same soil sample, the attachment is again made and the rate of percolation measured. This procedure of detaching, pouring off the water, and attaching again can be repeated as many times as desired.

While the rate of percolation of one soil is being studied, two or three other soils are soaking. In this way the rate of percolation of many soils can be studied in a single day.

Since suction is used, it is necessary that this remain quite constant for all experiments. The most practical vacuum to use, of course, is that of running water from a faucet. In most water systems the pressure remains sufficiently constant. In some, however, it may vary considerably. In the latter case, a regulating manometer can be used.

Another factor that tends to exert an influence on the suction and on the rate of penetration of water in the soil is temperature. Naturally this is to be expected, because temperature affects both the viscosity of water and the degree of vacuum produced. The best way to control the temperature factor is to use on the soil for percolation the tap water that has been running and which has attained its normal temperature The temperature of running tap water is comparatively constant, at least in most water systems

Finally, it must be emphasized again that the soil samples must not be pulverized but must be as much in their natural structure or lump condition as possible The process of slaking will then reduce them to a common structural basis.

EXPERIMENTAL DATA

If the method is followed as described and if all the precautions are taken, the method gives results that are consistent. In Table 1 are presented representative data which serve to give an idea (1) as to the uniformity of the results upon prolonged percolation after the initial 30 or 40 minutes percolation, (2) the degree of agreement or reproducability of results of duplicate experiments with the same soil, and (3) the relationship between colloidal content and rate of percolation in the various soils.

An examination of the results in Table 1 reveals many interesting facts. In the first place, it is readily seen that the method, as finally worked out, tends to give results that agree quite well, both in duplicate experiments as well as within the same experiment upon prolonged percolation. Though the results do not check as closely as might be desired, yet the disagreement is not much above 25% as a maximum as compared to almost 1,000% in the old methods.

In the second place, it is seen that the time required for 400 cc of water to pass through the soil column tends to increase with prolonged percolation, and this increase is much more pronounced in some soils than in others. It must be remembered that the measure-

TABLE 1.—*Showing general type of results obtained by the new percolation method.*

Soils	Number of 400-cc measurements on same soil sample after initial percolation	Minutes required for 400-cc of water to pass through soil after initial percolation		Colloids as determined by hydrometer method
		Sample 1	Sample 2	%
Quartz sand	1	1.20	1.35	0.0
	2	1.55	1.50	0.0
	3	1.60	1.70	0.0
Strong sandy loam	1	2.25	2.35	8.0
	2	2.30	2.40	8.0
	3	2.40	2.45	8.0
Portsmouth sandy loam	1	5.15	5.10	8.4
	2	5.40	5.32	8.4
	3	5.46	5.25	8.4
Susquehanna fine sandy loam	1	11.40	11.25	10.00
	2	11.30	11.36	10.00
	3	11.40	11.50	10.00
Fresno fine sandy loam	1	18.30	19.15	11.10
	2	19.35	19.50	11.10
	3	20.10	20.22	11.10
Napanee silt loam A	1	15.20	15.60	38.00
	2	15.20	18.80	38.00
	3	15.80	15.97	38.00
Miami silt loam A	1	18.25	19.00	22.00
	2	19.15	19.35	22.00
	3	19.85	20.05	22.00
Clyde silt loam from Minnesota	1	13.85	14.00	35.00
	2	14.15	14.20	35.00
	3	14.65	14.50	35.00
Grundy silt loam	1	28.50	29.00	34.00
	2	29.25	31.10	34.00
	3	31.00	31.60	34.00
Brookston silt loam A	1	18.30	17.90	25.5
	2	19.00	18.40	25.5
	3	19.10	19.00	25.5
Silty clay from Missouri	1	38.95	40.10	60.1
	2	41.10	42.25	60.1
	3	42.30	43.00	60.1
Residual clay from Michigan	1	21.20	22.35	83.00
	2	23.15	24.10	83.00
	3	24.85	25.60	83.00
Ontonagon clay B	1	12.00	11.85	72.50
	2	12.15	12.20	72.50
	3	12.25	12.55	72.50
Ontonagon calcareous clay C	1	22.00	23.80	85.00
	2	25.20	26.00	85.00
	3	26.00	26.95	85.00
Susquehanna clay C	1	12.45	13.15	58.00
	2	14.30	15.00	58.00
	3	15.10	15.85	58.00

ment of percolation was commenced after the soils had undergone an initial percolation of half an hour or longer. If the measurement of percolation was recorded from the very beginning, the figures would show still greater difference.

This tendency of the rate of percolation to become slower with time indicated that the soil column had not attained an equilibrium. On the other hand, it will be seen that most of the soils have almost reached equilibrium as the second and third readings do not show much variation. The soils that are very slow in attaining equilibrium are usually the highly colloidal clays, and especially those that tend to slake into finer particles or granules and which have high elasticity. It is natural to expect that such soils will be slow in attaining equilibrium or the same degree of compaction as the coarser textured soils. This property of elasticity introduces complication, prevents an absolute standardization of compactness, and consequently obscures many obvious relationships that are logical and natural to expect, as will be shown subsequently.

The thing that is probably of the greatest interest in connection with the percolation studies is the relationship between the rate of percolation and the colloidal content. The colloidal content of the different soils under investigation is shown in the fifth column of Table 1. This colloidal content was determined by the hydrometer method By comparing the percentage of colloids with the time required for 400 cc of water to percolate in the different soils, it is seen that, though there is a general tendency for the rate of percolation to be slower with the increase of colloidal material present, yet there are many exceptions to this general tendency. The rate of percolation in some heavy clay soils is faster or as fast as in some sandy soils with a comparatively small amount of colloids or clay present. For example, Fresno fine sandy loam contains 11% of colloids, and it required 20.16 minutes (average of the two experiments, third reading) for 400 cc of water to percolate through it, while Ontonagon clay B contains 72.50% of colloids and it required only 12.40 minutes for 400 cc of water to percolate through it. In a similar way, Napanee silt loam has 38% colloids and the percolation time was 15.89 minutes, while Grundy silt loam has 34% colloids and its percolation time was 31.30 minutes. On the other hand, Strongs sandy loam, Portsmouth sandy loam, Missouri silty clay, etc., tend to show that thereis a parallelism between colloidal content and rate of percolation.

In one sense, a definite correlation between colloidal content and rate of percolation should not be expected, while in another sense it should be. As to the former case, if the colloidal material did not exist in its ultimate texture or dispersed condition but in its ultimate natural structure, and providing that this natural structure was very stable and not too elastic, then there should not be any definite correlation, since the rate of percolation is mainly controlled by the present or immediate structure and not by the ultimate texture.

On the other hand, since the colloidal material, even in the granular structure, is more or less elastic and can be drawn together or easily compacted to a dense mass, such as exists in many clay. soils under field conditions, it would seem that there should be a general relationship between colloidal content and rate of percolation.

It would be of great interest and importance if the actual structural composition of the soils whose rate of percolation was studied was known. It was found very difficult to ascertain this, however, even by the method already developed and described for measuring the texture of the natural ultimate structure of soils.[4] The difficulty comes in the fact that after the soils are slaked they are more or less compacted into a layer by the suction, and it is almost impossible to disintegrate this layer into its natural structure without dispersing it. Of course, the natural ultimate structure of each soil could be determined in duplicate samples without subjecting them to suction, but this would not be a true measurement for the soil samples under experimentation.

Even if the actual structure of each soil were known, it is doubtful if the relationship between structure and rate of percolation that ought to exist would be clearly revealed, at least in some soils, because there are several other factors entering into such an unequal elasticity and stability of the colloidal granules in the different soils, tendency of the finest colloids to rise and collect at the top of soil layers, etc., which tend to mask the relationship from being revealed. In soils like Ontonagon clay B, in which the structure shows great stability and rigidity, the relationship between structure and rate of percolation is clear and unmistakable; but in soils like Grundy silt loam, silt loam from Missouri, etc., the elasticity and other factors disturb or destroy the relationship.

On the whole, it is safe to say that rapid percolation or good drainage go parallel with coarse or granular structure. If the coarse or granular structure of the clay portion of soils is destroyed and reduced to the ultimate texture, percolation almost stops or becomes exceedingly slow. A good example of this is afforded by Ontonagon clay B. It is seen in Table 1 that when this soil is allowed to slake or disintegrate into its natural structure, the percolation is at the rate of 400 cc per 12.40 minutes; that when this soil is dispersed by the special dispersing machine, the percolation is at the rate of 400 cc per 1,600 minutes, or 26.6 hours.

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[4] Bouyoucos, G. J. The ultimate natural structure of soils. In press.

Although rapid percolation or good drainage tend to accompany coarse or granular structure, yet the dominant influence of this coarse structure can be entirely overcome by a very small amount of dispersed colloids or fine material placed in certain positions. For instance, if a layer or column of soil is composed of coarse or granular structure and if a very thin layer of fine colloids should settle at the top of the soil column, the dominant if not the controlling influence on percolation will be exerted, not by the coarse structure in the column, but by the very thin layer of colloids at the top.

The question that may now be asked is, do the percolation results shown in Table 1 indicate the actual permeability of the different soils under field conditions?

It must be clearly borne in mind that all soils, except sand, have a tremendously wide range of permeability, both under laboratory and under field conditions. In clays, for instance, the permeability may range from a very rapid rate of flow, such as takes place in coarse sands, to almost absolute imperviousness.

All that can and should be expected from this laboratory percolation method is to show the comparative permeability of the different kinds of soils under a comparative or similar set of conditions, or to show reliably the permeability of any one soil under different sets of conditions or treatments; but it should not be expected to show the permanent or absolute permeability of soils, because there is no permanent or absolute permeability of soils either under laboratory or field conditions.

VIGOR IN SOYBEANS IN RELATION TO INHIBITION OF PUBESCENCE[1]

COLLINS VEATCH[2]

It has been reported by Nagai and Saito (1)[3] and by Owen (2) that the dominant factor P_1 which inhibits the development of pubescence also reduces the vigor and delays the development of the soybean plant (*Soja max Piper*). Wentz and Stewart (4) found that the recessive glabrous factor p_2 had little, if any, effect on plant development when in the heterozygous condition, although the plants homozygous for p_2 were greatly reduced in size and vigor below the pubescent type. Data on plant development secured from three crosses involving the factor P_1 are presented here.

MATERIAL AND METHODS

The four lines of soybeans used in these crosses were furnished by Doctor C. M. Woodworth and have been carried on as pedigree strains from single plants. The line designated as 435B was secured several years ago as a segregate from a cross between Medium Green and a dominant glabrous soybean. This line carries the factor P_1 which inhibits the expression of pubescence. The three other strains are pubescent. The Wea strain is a selection from the Wea variety. The "Chimera" strain came from a Chimera soybean plant. One side of this plant was purple-stemmed and bore purple flowers, while the other side was green-stemmed and bore white flowers The Chimera strain came from the green-stemmed, white-flowered part of the plant. The strain designated as 339 is a U. S. Dept. of Agriculture introduction, the 339 being an abbreviation of the U. S. P. I. No. 65339.

In 1927, the F_1 seeds and seeds from the parental plants were planted in small paper pots in the greenhouse May 17 and transplanted to the field June 1. These plants were spaced 1 foot apart in rows 2 feet apart. Two plants of one parental line were planted on one side of the hybrid and two plants of the other parental line on the other side. The following year the F_2 seeds were planted 6

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[1] Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois. Published with the approval of the Director of the Station. Received for publication November 20, 1929.

[2] Formerly Graduate Student in Plant Breeding, University of Illinois; now with the Compañia Agricola, S. F. de Macoris, Dominican Republic. The author wishes to express his appreciation of the suggestions given by Dr. C. M. Woodworth during the progress of this study and also for the encouragement and assistance in the preparation of the manuscript.

[3] Reference by number is to "Literature Cited," p. 452.

inches apart in rod rows 2 feet apart, alternating rows of the parental lines with rows of the F_2 population.

F_1 RESULTS

WEA X 435B

The F_1 plant resembles the dominant glabrous type in vigor as well as in lack of pubescence when the normal pubescent soybean is crossed with the dominant glabrous type. The Wea x 435B F_1's averaged 46.5 cms in height and produced 108.5 seeds per plant (Table 1). The Wea plants grown in comparison with these hybrids averaged 90 cms in height and produced 371 seeds per plant, while the 435B plant was 44 cms in height and produced 100 seeds. In this cross the average of the hybrids was below the parental average in the characters denoting desirable plant development, such as plant weight, plant height, total stem and branch length, number of seeds, and number of pods per plant (Table 1). However, the hybrids slightly exceeded the parental average in straw-grain ratio, number of nodes, and average seed weight. The hybrids were later in flowering than either parent and carried almost as many abortive seeds as the more abortive 435B parent.

TABLE 1.—*Comparison of average of two Wea X 435B hybrids with the parental strains for the various characters indicated*

Character	Parents			Hybrid*	Increase of hybrid over average of parents	
	Wea*	435B	Average		Actual	%
Seed weight, grams.	59.650	11.720	35.690	15.270	—20 420	—57.21
Plant weight, grams	110.500	24.000	67.250	29.000	—38 250	—56.88
Straw-grain ratio . . .	1.170	0.950	1.060	1.110	0.050	4.72
Plant height, cms .	90.000	44 000	67 000	46 500	—20 500	—30.60
Total stem and branch length, cms . .	390.000	142.000	266.000	200.500	—65.500	—24.62
Number nodes	81.500	86.000	83.750	86 500	2.750	3.28
Average internode, cms	4.790	1.650	3.220	2.320	— 0.900	—27.95
Number seeds	371.000	100 000	235.500	108 500	—127.000	—53.93
Average seed weight, grams	0.161	0.117	0.139	0.141	0.002	1.44
Number pods . . .	163 000	71.000	117.000	61.500	—55.500	—47.44
Number seeds per pod .	2.280	1.410	1.850	1.760	— 0.090	— 4 86
Abortive seeds, % . .	4.130	27.000	15.570	25.680	10.110	64.93
Days to flowering . .	45.000	66.000	55.500	72.500	17.000	30.63

*Average of two plants.

CHIMERA X 435B

The Chimera x 435B F_1 did not show a very marked difference from the parental average. It produced 70 seeds and was 30 cms in height (Table 2). The Chimera plant, grown in comparison with this F_1, produced 72 seeds and was 24 cms in height, while the 435B plant produced 62 seeds and was 34 cms in height. This hybrid was below the parental average in seed weight, plant weight, total stem and branch length, number of nodes, average length of internode, average seed weight, and number of pods. However, it exceeded the parental average in straw-grain ratio, plant height, number of seeds, number of seeds per pod, percentage of abortive seed, and number of days from planting to flowering.

TABLE 2.—*Comparison of the Chimera X 435B hybrid with the parental strains for the various characters indicated.*

Character	Parents			Hybrid	Increase of hybrid over average of parents	
	Chimera	435B	Average		Actual	%
Seed weight, grams.. ..	15.680	7.540	11.610	10.440	— 1.170	—10.08
Plant weight, grams. .	30.500	15.000	22.750	20.500	— 2.250	— 9.89
Straw-grain ratio	1.060	1.010	1.035	1.038	0.003	0.28
Plant height, cms .	24.000	34.000	29.000	30.000	1.000	3.45
Total stem and branch length, cms .	87.000	145.000	116.000	89.000	—27.000	—23.28
Number of nodes .	51.000	107.000	79.000	64.000	— 15.000	—18.99
Average internode, cms	1.710	1.360	1.535	1.390	— 0.145	— 9.45
Number seeds .	72.000	62.000	67.000	70.000	3.000	4.48
Average seed weight, grams	0.218	0.122	0.170	0.149	— 0.021	—12.35
Number pods	49.000	47.000	48.000	43.000	— 5.000	—10.42
Number seeds per pod .	1.470	1.320	1.395	1.630	0.235	16.85
Abortive seed, %	5.260	0.160	2.710	6.670	3.906	146.13
Days to flowering	53.000	68.000	60.500	63.000	2.500	4.13

339 X 435B

The 339 x 435B F_1 was below the parental average in seed weight, number of seeds per plant, and average seed weight (Table 3). This hybrid produced 41 seeds and flowered 67 days after planting. The 339 plant, grown in comparison with this hybrid, produced 172 seeds and flowered 47 days after planting, while the 435B plant produced only 36 seeds and flowered 70 days after planting. The 435B plants grown in comparison with this hybrid were threshed without taking measurements or records on the plants. That is why all such records are omitted from Table 3.

TABLE 3.—*Comparison of the 339 X 435B hybrid with the parental strains for the various characters indicated.*

Character	Parents			Hybrid	Increase of hybrid over average of parents	
	339	435B	Average		Actual	%
Seed weight, grams.....	31.370	5.320	18.345	5.820	—12.520	—68.27
Number seeds	172.000	36.000	104.000	41.000	—63.000	—60.58
Average seed weight, grams...	0.182	0.148	0.165	0.142	— 0.023	—13.94
Days to flowering......	47.000	70.000	58.500	67.000	8.500	14.53

F_2 RESULTS

On account of the small number of seeds produced by the F_1 plants, the F_2 progenies were rather limited. However, the results will give an indication, at least, of what one could expect in such crosses. The genotypic constitution of the glabrous F_2 plants with respect to the P_1p_1 factor pair was determined by growing the F_3's in the greenhouse, since the presence or absence of pubescence can readily be determined in the seedling stage.

TABLE 4.—*Comparison of the F_2 and parental populations in yield of seed.*

Strain*	Character of plants	Number of plants	Mean yield in grams	Range		W
				Minimum	Maximum	
Wea	Pubescent	106	25.39±0.54	4.60	45.46	2.60
(p_1p_1)	Pubescent	37	42.05±1.27	24.76	64.16	3.68
F_2 (P_1p_1)	Glabrous	92	8.83±0.25	2.50	19.30	1.77
(P_1P_1)	Glabrous	47	8.37±0.31	2.88	14.80	1.85
435B	Glabrous	78	5.56±0.18	1.26	11.36	1.53
Chimera	Pubescent	55	14.61±0.41	3.31	24.95	1.94
(p_1p_1)	Pubescent	11	25.13±1.81	5.18	41.36	2.97
F_2 (P_1p_1)	Glabrous	29	7.24±0.40	1.34	15.24	1.74
(P_1P_1)	Glabrous	17	7.60±0.56	2.64	14.90	1.98
435B	Glabrous	29	6.19±0.41	2.88	12.15	2.22
339	Pubescent	26	23.40±0.36	8.50	49.90	0.87
(p_1p_1)	Pubescent	7	32.40±3.18	8.41	49.70	4.18
F_2 (P_1p_1)	Glabrous	16	8.59±0.58	2.42	14.88	1.95
(P_1P_1)	Glabrous	6	10.24±0.86	3.86	13.15	2.20
435B	Glabrous	16	7.47±0.54	2.85	13.55	1.99

*p_1p_1 = pubescent F_2 segregates, P_1p_1 = heterozygous glabrous F_2 segregate, and P_1P_1 = homozygous glabours F_2 segregates.

YIELD

The pubescent parental strains and pubescent segregates in the F_2 populations averaged higher in yield than the glabrous types (Table 4). On the average, the pubescent parents yielded more than twice as much as the glabrous parental type The Chimera strain was the lowest yielding pubescent parental type and it averaged 14.61 ± .41 grams of seed, while the 435B glabrous strain averaged only 6.19 ± .41 grams of seed per plant.

The pubescent F_2 segregates not only outyielded the glabrous segregates but were significantly higher in mean yield than the pubescent parental lines. There was no significant difference between the average yields of the F_2 segregates that were homozygous and those that were heterozygous for the factor P_1. On the average, the F_2 glabrous segregates yielded somewhat higher than the glabrous 435B parents.

The F_2 populations showed a greater range in yield than the parental varieties, although the difference is small in the case of the 339 x 435B cross. Measuring the variability by Weinberg's

(3) formula, the F_2 pubescent segregates were more variable in yield than any of the other populations in these crosses (Table 4). This high variability is due to the small number of plants of this type produced as well as to the great range. The great range is probably due to the segregation of factors determining growth and yield.

NUMBER OF SEEDS PER PLANT

As one would expect, the data on seed number show relationships very similar to those of the data on yield. The mean number of seed produced by the F_2 pubescent segregates was higher than the mean for the parental populations in these crosses (Table 5). The variability was also higher for the F_2 pubescent segregates than for the parents. One interesting feature is that in yield the maximum variate of the 339 strain slightly exceeded the F_2 segregates, while in number of seeds per plant there were two plants in the F_2 each of which produced more seeds than any 339 plant.

TABLE 5.—*Comparison of the F_2 and parental populations in number of seeds per plant.*

Strain	Character of plants	Number of plants	Mean number of seeds per plant	Range		W
				Minimum	Maximum	
Wea	Pubescent	106	205.70± 4.13	36	340	2.30
(p_1p_1)	Pubescent	37	355.50±12.49	175	625	10.83
F_2 (P_1p_1)	Glabrous	92	74.60± 2.42	17	183	5.60
(P_1P_1)	Glabrous	47	76.91± 3.27	20	151	5.87
435B	Glabrous	78	54.05± 1.86	11	115	4.86
Chimera	Pubescent	55	102.16± 2.87	18	177	5.01
(p_1p_1)	Pubescent	11	214.09±15.61	52	345	9.03
F_2 (P_1p_1)	Glabrous	29	59.83± 3.68	14	127	5.63
(P_1P_1)	Glabrous	17	61.82± 4.79	19	126	5.77
435B	Glabrous	29	62.00± 3.75	23	134	5.95
339	Pubescent	26	169.15± 7.38	61	293	7.35
(p_1p_1	Pubescent	7	239.00±23.60	74	359	11.12
F_2 (P_1p_1)	Glabrous	16	63.75± 4.40	14	104	5.54
(P_1P_1)	Glabrous	6	79.33± 7.27	34	106	6.45
435B	Glabrous	16	69.38± 5.36	28	129	6.43

PLANT HEIGHT

Considering the difference in the height of the parental strains, one would expect considerable variation in the F_2 (Table 6). In all three crosses the F_2 range in height was greater than the parental range. The F_2 populations were divided into three groups according to the genotype in respect to the factor P_1 and the variability measured by Weinberg's (3) formula. In the Chimera x 435B cross, the Chimera strain was the most variable, while in the other two crosses the pubescent segregates were the most variable as shown by the value of W. The F_2 pubescent segregates averaged taller than the pubescent parents in all three crosses. There was no significant difference in the mean heights of the heterozygous (P_1p_1) and the homozygous (P_1P_1) glabrous segregates. In the case of the Wea x 435B cross the mean height of the F_2 glabrous types was significantly higher than the mean height of the glabrous 435B parental strains.

TABLE 6.—*Comparison of the F_2 and parental populations in plant height.*

Strain	Character of plants	Number of plants	Mean height, cms	Range		W
				Minimum	Maximum	
Wea	Pubescent	106	81.70±0.65	57	100	3.04
(p_1p_1)	Pubescent	37	84.91±2.03	53	135	4.15
F_2 (P_1p_1)	Glabrous	91	41.88±0.82	13	62	3.36
(P_1P_1)	Glabrous	47	42.53±0.92	18	80	2.43
435B	Glabrous	78	33.18±0.43	13	45	2.07
Chimera	Pubescent	54	46 85±1.05	27	58	4.29
(p_1p_1)	Pubescent	11	52.64±1.66	32	63	3.11
F_2 (P_1p_1)	Glabrous	29	33.79±0.71	18	43	2.33
(P_1P_1)	Glabrous	17	34.06±0.97	24	46	2.53
435B	Glabrous	29	34.48±0.67	25	44	2.47
339	Pubescent	26	58.19±0 58	47	64	2.26
(p_1p_1)	Pubescent	7	69.00±4.40	39	96	4.59
F_2 (P_1p_1)	Glabrous	16	40.69±1.01	26	52	2.36
(P_1P_1)	Glabrous	6	45.50±3.10	24	55	4.38
435B	Glabrous	16	38.25±0.95	28	47	2.60

DISCUSSION

The F_1 plants were below the parental average, as previously shown, in many of the desirable characteristics denoting vigor and development. The difference between the pubescent parent and the hybrid was most marked in the Wea x 435B cross. This may be readily explained by the fact that the Wea strain is, on the whole, a higher producing type than either of the other two pubescent strains used in these crosses.

Taken as a whole the F_2 pubescent segregates were more vigorous as well as more variable than the pubescent parental strains. This suggests that the glabrous parent contributed certain factors for vigor to the hybrid other than those contributed by the pubescent parent. The F_2 pubescent segregates were grown in rows with the glabrous F_2 plants and were possibly not limited so much by competition as were the pubescent parental plants. However, the plants were all spaced 6 inches apart in the row so that competition should have played little or no part in plant development. Similarly, the F_2 glabrous plants evidently received certain favorable growth factors from the pubescent parent, since they were on the average more vigorous than the glabrous parental strain.

The results show a close relationship between vigor or plant development and pubescence. The factor P_1 either has a double inhibiting effect in that it inhibits or reduces vigor and plant development as well as pubescence, or it is very closely linked with factors reducing vigor. In the F_2 of these crosses the maximum glabrous plants were below the average of the pubescent types in plant height. In two of the crosses, the maximum glabrous plants were below the means of the pubescent types in yield and number of seeds produced. In the case of the Chimera x 435B cross, the maximum glabrous F_2 plant yielded better than the mean of the pubescent Chimera parent, but less than the mean of the pubescent F_2 segregates. However, there were pubescent segregates in the F_2 and plants of the pubescent parental lines that did not yield as much as certain of the F_2 glabrous plants. Hence, in this cross, there were evidently other factors than those associated with P_1 which had a modifying influence on vigor or plant development.

SUMMARY

In these soybean crosses involving the dominant factor P_1 which inhibits the expression of pubescence, the vigor of the F_1 was below the average of the parents. In most of the characters studied the hybrid resembled the glabrous 435B more than the pubescent parent. The hybrids were all later than the average of the parents in flowering and the Wea x 435B hybrids were later than the late 435B parent.

The F_2 results indicate a close relationship between pubescence and vigor or plant development. The recessive pubescent F_2 segregates averaged higher than the glabrous parents in height and number of seeds per plant There was no significant difference in the development of the glabrous F_2 plants that were heterozygous and those that were homozygous for the factor P_1. The glabrous parental plants were comparatively small and poorly developed. The evidence indicates that there is a very close relationship between the factor P_1 and vigor. The factor P_1 either has a double effect in reducing vigor as well as inhibiting pubescence or is very closely linked with factors that reduce vigor and development.

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PLANT CHARACTERS AS INDICES IN RELATION TO THE ABILITY OF CORN STRAINS TO WITHSTAND LODGING[1]

H. K. WILSON[2]

Preliminary observation and experiments indicate that certain growth habits of the corn plant in the greenhouse are associated with field performance. The object of the present paper is to present data supporting the theory that certain morphological differences of corn plants may be used as indices of the ability of strains to withstand lodging under field conditions.

TECHNIC

Certain self-fertilized lines of Minnesota No. 13, Rustler, and Northwestern Dent, which were being used as parents of F_1 and double crosses, were selected on the basis of lodging data, a summary of which is given in Table 1.

TABLE 1 —*Lodging of self-fertilized lines in corn breeding plats, 1926–28.*

Variety	Culture No.	1926 %	1926 Degree	1927 Score	1928 index	Classification
Minn. No. 13	41	45	5	1	27.5	Midstrong
Minn. No. 13	42	74	10	2	32.5	Midstrong
Minn. No. 13	43	92	50	1	38.8	Weak
Minn. No. 13	44	92	60	2	43.1	Weak
Minn. No. 13	49	37	10	0	13.7	Strong
Rustler	51	66	10	1	12.5	Strong
Rustler	54	100	70	2	49.1	Weak
Rustler	57	100	80	4	47.7	Weak
Rustler	60	100	15	2	26.3	Midstrong
N. W. Dent	64	0	0	0	0.1	Very strong
N. W. Dent	65	100	60	0	41.6	Weak
N. W. Dent	66	100	60	3	45.5	Weak
N. W. Dent	67	100	30	0	36.0	Midstrong
N. W. Dent	68	40	10	1	16.3	Strong

The 1926 data were obtained from single rows and are presented on the basis of the percentage of the lodged plants. The average degree or angle of inclination from perpendicular is given in connection with the percentage lodging. The score for 1927 was an estimate of lodging on the basis of an examination of individual rows, 0 representing no lodging and 5 representing severe lodging. The data in 1928 were obtained from three plats, two of which were in connection with yield studies and the third a single row in the breeding nursery. In the latter year, a severe storm occurred a few days after pollination. This resulted in considerable lodging. Individual plants were placed in four groups on the basis of the angle of inclination. A calculated index was obtained by multiplying the number of stalks in each group by the angle of inclination and dividing the product by the total number of stalks. On the basis of the data for the three years, strains were classified as very strong, strong, midstrong, and weak.

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[2] Assistant Agronomist. The author wishes to express his appreciation for the selfed lines and the data given in Table 1, furnished by Dr. H. K. Hayes, Chief of the Department of Agronomy and Genetics.

On October 27, 1928, seed of seven lines was planted in greenhouse beds providing sufficient space for full development. Each plant was allotted an area 18 x 36 inches. All strains were replicated three times. The plants were grown without artificial light and reached maturity January 25, 1929, on which date they were harvested Soil was carefully removed from each plant to prevent the loss of any roots.

Following the greenhouse studies, the work was expanded to include a total of 14 selfed lines of the three original varieties. These were grown in the field in individual sewer tile 30 inches in diameter. Each tile was sunk into the ground to provide small individual plats. Strains were replicated six times. The stand was thinned to provide one plant to each plat. A lever of the second class was used to determine the resistance of individual plants to a vertical pull.

EXPERIMENTAL DATA

GREENHOUSE RESULTS

As a result of insufficient light, all plants made rather weak growth. It was surprising to note that considerable lodging occurred. Apparently, the light deficiency resulted in weakened plant development. Those plants failing to develop brace roots lodged, while the strains with shortened internodes and numerous buttress roots were erect in growth.

The close relationship between field performance and greenhouse conditions is evident (Table 2), every strain having lodged in the field behaving in a similar manner in the greenhouse. Plant height appears to be associated with the vigor of the particular strain and to be unrelated to lodging.

The development of brace roots was very important in the prevention of lodging. With the exception of culture No. 65, no brace roots were developed by the strains which lodged severely under field conditions. In culture No. 65, one plant developed four brace roots while the replicates produced none.

TABLE 2.—*Data showing the behavior of selfed lines of corn grown in the greenhouse in relation to lodging tendencies.*

Variety	Culture No.	Field classification	Lodging in % from —	Plant height, cms	Brace roots Nodes bearing	Brace roots Functional	Secondary roots No.	Secondary roots Diameter and length, mm	Dry weight of all roots, grams	Length of 3 lowest internodes in mm First	Second	Third	Total
Minn. No. 13...	43	Weak	83	38	0.0	0.0	19	141	0.2166	27	40	47	114
Minn. No. 13. .	49	Strong	0	35	2.0	4.6	12	149	0.2491	4	24	42	70
Rustler...	51	Strong	0	80	2.5	13.0	16	170	0.5404	6	18	42	66
Rustler . ..	54	Weak	47	50	0.0	0.0	12	230	0.2875	41	46	50	137
N. W. Dent .	64	Very strong	5	43	2.0	7.1	9	141	0.2993	7	23	47	77
N. W. Dent . .	65	Weak	47	54	0.3	1.3	15	214	0.3101	23	47	52	122
N. W. Dent .	68	Strong	7	44	2.0	8.0	12	137	0.2533	8	27	47	82

TABLE 3.—*Plant characters of pure lines of corn in relation to lodging of plants grown in individual plats in the field, University Farm, 1929.*

Strain	Culture No.	Previous field behavior	Lodging % from—	Diameter lowest internode, mm	Height, inches	Resistance, pounds	Internode length in mm First	Second	Third	Total
Minn. No. 13	41	Midstrong	0	16.62	47	128.0	12	27	47	86
Minn. No. 13	42	Midstrong	19	16.78	52	138.5	16	40	51	107
Minn. No 13	43	Weak	61	15.01	46	96.5	18	42	68	128
Minn. No. 13 .	44	Weak	43	15.89	55	70.4	17	40	59	116
Minn. No. 13 .	49	Strong	0	17.16	38	122.5	10	21	39	70
Rustler . .	51	Strong	0	22.47	46	166.3	8	12	21	41
Rustler .	54	Weak	46	20.21	37	65.4	14	27	50	91
Rustler .	57	Weak	90	17.84	50	67.3	20	35	59	114
Rustler.	60	Midstrong	38	18.75	50	108.5	10	19	32	61
N. W. Dent . .	64	Very strong	0	15.38	54	133.6	12	24	49	85
N. W. Dent ..	65	Weak	34	11.29	36	42.5	14	27	58	99
N. W. Dent .. .	66	Weak	16	19.17	47	65.8	13	34	52	99
N. W. Dent.	67	Midstrong	7	14.92	48	100.0	10	23	55	88
N. W. Dent .	68	Strong	0	15.27	36	120.8	11	23	43	77

The development of secondary roots was not related to the lodging character. In some cases the weak strains developed greater root area than the strong. This relationship probably does not hold for field conditions, as will be brought out later. Diameter x length represents the average index for the secondary roots of each strain. The number of secondary roots does not include the brace roots. This places the strong strains at some disadvantage in the data given. If, for example, the 13 brace roots developed by culture No. 51 were included, the figure would be much greater. The influence of these brace roots is shown in the greater dry weight of all roots. Culture No. 65, a weak strain, produced greater total weight of roots than the strong strains 64 and 68 because of the greater development of the secondary root system.

The length of the three lowest internodes bore a striking relationship to brace root development and resistance to lodging. In the strong strains the nodes were much closer together. In no case did the combined length of the three internodes of the so-called strong strains exceed 82 mm, while in the weak strains the lowest total length was 114 mm It is well recognized that the short internodes of grasses give rigidity to the plant, whether brace roots develop or not. Further, the corn plant can develop roots at any node coming in contact with the soil. Thus under average farming conditions where the soil is thrown to the plant, nodes near the surface may have greater opportunity for brace root development. However, the validity of this hypothesis has not been determined.

FIELD INVESTIGATIONS

As a further study of the problem, the investigations were carried to the field in 1929 with an added number of strains. Correlation between previous field behavior and lodging in 1929 was not perfect (Table 3), but it was close enough to be highly significant. Rustler, culture No. 60, was the only strong strain to lodge to an appreciable extent. Measurements of the diameter of the lowest internode failed to disclose any significance in this character to the problem in hand.

Height in inches was related to the genetic constitution of the strain as in the greenhouse studies. The Northwestern Dent strains did not bear the same height relationships as in the greenhouse, but in no way did this appear related to lodging.

The resistance in pounds to a sustained pull presents interesting data. In every case the strong strains of each varietal group gave greater resistance. In the Minn. No. 13 strains, the average resistance of the weak strains was 83.5 pounds and for the strong strains 129.7

pounds. The weak Rustler strains averaged 66.4 pounds and the strong 137.4 pounds. Northwestern Dent weak strains gave a resistance of 54.2 pounds and the strong 118.1 pounds.

No actual measurements were made of root size, but it was evident that, including brace roots, the entire root system was greatest in the strong cultures.

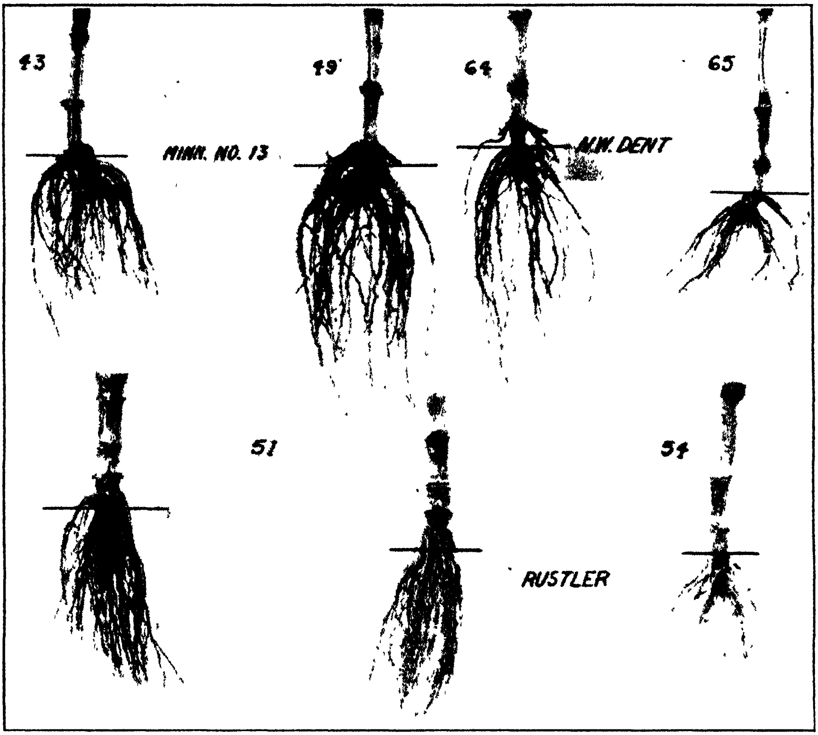

FIG. 1.—Typical root systems of the weak (left) and strong (right) strains of Minn. No. 13, N. W. Dent, and Rustler selfed lines, respectively. Two systems of culture No. 51 are included.

The length of the three lowest internodes was associated with lodging resistance as in the greenhouse. The averages of the total length of the three internodes in mm were as follows:

	Weak	Midstrong and strong
Minn. No. 13	122	88
Rustler	103	51
N. W. Dent	99	83

The above data bear out the preliminary greenhouse results as given in Table 2. Brace roots developed on the cultures with the short internodes as shown in Fig. 1. Culture No. 51 was outstanding in resistance to lodging and in the development of numerous brace roots which penetrated the soil to great depth, serving as means of support and increasing the feeding area greatly. This strain, it will be recalled, developed 13 functional brace roots in the greenhouse trials (Table 2).

SUMMARY

Selfed strains of corn were used in the investigations. These were selected on the basis of three years study of lodging in the field. The strains were relatively homozygous and were being used in breeding studies to determine their desirability as parents of single and double crosses.

Preliminary investigations in the greenhouse and field indicate that the distance between the lower internodes of the corn plant and accompanying development of brace roots may be useful in predicting the probable resistance of selfed lines to lodging under field conditions. It is suggested that growing corn plants in the greenhouse with insufficient light, as under winter conditions, may produce lodging in a manner similar to field performance.

ABSORPTION OF WATER BY PLANTS AND THE FORCES INVOLVED[1]

CHARLES A. SHULL[2]

The water relations of plants have long been recognized as of very great importance, and as a consequence, much attention has been given to them. In the very beginnings of experimental plant physiology after the Renaissance it was mainly water relations that were studied. The early experiments of Van Helmont (33),[3] of Woodward (37), and of Hales (9) all centered about the intake and utilization of water by plants. Hales spent ten years in active investigation of absorption, sap pressure, sap rise, and the elimination of water from the leaves of plants. Two centuries have gone by. We have made great strides in our analyses of the problems, and the actual gain in knowledge has been considerable Nevertheless, we are still deeply concerned with these fundamental life conditions and processes, in some phases baffled by their complexity, in others quite uncertain as to the correctness of our interpretations of the observed phenomena. New modes of attack are being sought, and new points of view brought forward Some of the most widely accepted interpretations of root behavior are being challenged, and it is therefore necessary to keep our minds open to the flux of new ideas in this field

In discussing the intake of water by the roots of plants, I am sensible of the fact that absorption is the final consequence of the disturbance of water equilibrium within the tissues of the organism. It would be more logical, therefore, to consider these features of the water relations in the final rather than in the opening section of this symposium. The development of a saturation deficit and its transmission from leaves to roots has been discussed more fully in an earlier paper (28), and will not be considered here. It will be assumed from the beginning that the water deficit already exists in the root tissues as the result of transpirational loss of water from the leaves, and the transmission of the leaf tissue deficit through cohesive water columns to the root region.

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[1] Presented as part of a symposium on the "Water Relations of Plants" at the annual meeting of the Society held in Chicago, Ill., November 18, 1927. The symposia papers were never assembled for publication, and this paper is published at this time following requests from various sources that the material presented herein be made available in this form. The other papers presented at the symposium were as follows: "Cell Concentration in Relation to Absorption and Transpiration," by J. Arthur Harris; "Water in Growth and Activity," Charles F. Hottes; and "The Relation of Transpiration Loss to Atmospheric Conditions," by H. L. Shantz.

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[3] Reference by number is to "Literature Cited," p. 469.

It may be useful to point out some general features of the water relations before entering upon a discussion of the forces involved in the unidirectional transfer of water from soil to xylem vessels. The degree of turgidity of the cells and the degree of water deficiency in the plant tissues depend upon the relative rates of water loss and water income--of transpiration and of absorption. If the former exceeds the latter, turgidity decreases; but if the relations are reversed, there is a recovery of turgidity. Transpiration and absorption are so related that the rate of water loss from the leaves may frequently depend largely upon the rate of absorption by the root. Conversely, the rate of water intake by roots may at times be largely determined by the rate at which transpiration proceeds During growth absorption on the whole occurs more rapidly than transpiration, so that there is an accumulation of water, both free and combined, in the plant body. In the ripening stages or late maturity of the life cycle, transpiration exceeds absorption, and the plant body gradually dries out and finally dies, in the case of our annual plants. Furthermore, the rate of absorption is often limited by the amount and condition of water in the soil. The plant and soil may, then, be looked upon as a single complex system in which water is held and transported by kinetic physical, chemical, colloidal, and electrical forces peculiar to the system.

The whole relation of the root and soil to the soil water is a dynamic one, and it must be considered from the standpoint of those forces which cause diffusion, colloidal and chemical hydration, osmotic action, and electric transfer of water. On careful consideration one becomes impressed with the fact that in water itself resides the main dynamic power with which we have to deal; that when free water exists more abundantly anywhere in the system than at some other part, this free water moves with great kinetic power toward the place where a deficit of free water has been produced, provided there is a suitable pathway, a water-permeable pathway, along which water diffusion can take place. The average kinetic force of the water molecule at room temperature has been estimated (28) at about 1,350 atmospheres, but its movement will be governed by the *difference* between the forces causing a forward movement and those resisting that movement. The difference does not have to be great to develop considerable power of migration, as we shall see later. A water deficit which reduces vapor pressure of the cell colloids by 7% below that of pure water is believed to develop forces close to 100 atmospheres.

Before entering upon a consideration of these forces which are involved in the absorption processes of roots, we must make brief reference to the structural features of the younger portions of roots where absorption is most active.[4] It has been generally believed that the main absorptive portion of the root system is the root hair region. The activity of root hairs has been for the most part assumed, partly on the basis of their structure and chemical composition, and partly on their intimate connection with the soil particles from which they are believed to obtain the moisture which they absorb. Most certainly it is the younger portions of the root system that do the main work of absorption, but the efficacy of root hairs has recently been seriously questioned

A cross section of the root in the region where differentiation is taking place reveals a mass of cells which are changing over into xylem cells, appearing in cross section as diarch, triarch, tetrarch, or polyarch bundles, that is, with two, three, four, or more numerous points of origin of xylem from the undifferentiated parenchyma of the young root tissue. The protoxylem cells, or earliest cells to differentiate, lie in contact with the thin-walled cells of the pericycle which surrounds the whole vascular system, and with it forms the stele. Just outside the pericycle is a layer of cells which has been called the endodermis This layer of cells has usually been considered the inner layer of the cortex, and it is similarly thin-walled in the region of early differentiation. These endodermal cells are girdled on their radial and end walls by a strip of at least partially water-proofed material which forms the Casparian strip This cutinized, suberized, or otherwise modified thickening of the wall is believed to prevent the passage of water in any large amount through the walls thus thickened, and to necessitate the passage of water and solutes through the protoplasm of these cells, since the protoplasm remains in contact with the Casparian strips even when the cells have been plasmolyzed. The endodermis has been credited by several investigators (7, 8, 17, 19, 20, 21) with special semipermeable properties on account of the nature of the Casparian strips and their relation to the living protoplasm.

Outside the endodermis, the cortex is made up of thin-walled cells, and these are bounded by the epidermal cells with their root hairs, which are also thin-walled. There exists, then, a complete pathway

[4] I am indebted to Prof. H. E. Hayward for a critical reading of this and the succeeding paragraph.

of thin-walled cells from the root hairs or other epidermal elements across the cortex, through the endodermis and pericycle, to the xylem strands. It is fairly certain that water follows this pathway of thin-walled cells, probably penetrating the undifferentiated elongating cells below the root hair region as freely as the root hairs themselves, in proportion to the area exposed to the soil.

Turning now to the forces involved in the intake of water, the first cause of saturation deficit in the root is a more rapid removal of water from the living cells into the xylem than of intake and transfer of water from epidermis to pericycle. It is my belief that this removal of water from the pericycle, endodermal, and inner cortical cells is due to the tensional pull of the tracheal water columns first upon the water in the cell walls and protoplasm of the living cells abutting upon the tracheae, and through these colloidal structures, upon the water of the vacuoles of these abutting cells. It is proved beyond question that a positive pressure upon a solution can be used to force pure solvent through a perfect semipermeable membrane against the osmotic diffusion of water (4). There is no inherent reason, then, why the tensional pull of the tracheal columns may not pull water from these living pericycle cells against their osmotic pressure, whenever that pull exceeds the osmotic value of the cell sap of the inner living cells of the root.

If we do remove water from these vacuoles into the tracheae, the free water of these vacuoles is reduced, and osmotic action begins to transfer water from more remote vacuoles to those nearest the xylem. In this transfer of water from vacuole to vacuole, the intervening colloids between two vacuoles must possess a hydration gradient which assists in the transfer of water across the colloidal membranes. By the osmotic action, the saturation deficit which first arose in the cell walls and protoplasm in contact with the protoxylem strands is transmitted in a peripheral direction, until finally even the epidermal cells are affected, and develop a saturation deficit. As a result of this chain of events, we have a water deficit gradient set up in the root tissues. The deficit is greatest in the inner regions of pericycle and cortex, and least in the epidermal region. Careful examination of the epidermal and cortical cells reveals the existence of an osmotic pressure gradient across the root, a diffusion gradient for water movement inward.

During recent years Ursprung (30, 31, 32) and his coworkers and students have raised objections to the use of the term osmotic pressure in connection with the intake of water and turgidity of plant cells. The term proposed to replace osmotic pressure is "suction force" of the cell. Suction force has been defined as the difference between the "suction force" of the contents of the cell and the wall pressure of the stretched cell wall pressing back upon the expanding contents. If the "suction force" of the contents is 8 atmospheres and the resilient wall presses upon the protoplasm with a force of 2 atmospheres, then the "suction force" of the cell is only 6 atmospheres. Ursprung would say that there is a gradient of "suction force," rather than a gradient of osmotic pressure across the living root cells to the xylem.

A valuable service has been done by Ursprung and his associates in making osmotic pressure measurements more accurate, and in arriving at truer values of the effective forces; but the term "suction force," it seems to me, has been an unfortunate choice of terms. Even suction tension (3) is scarcely more satisfactory. These terms imply that the cell contents have a power to expand and draw water into the cell, as if to fill a partial water vacuum caused by the expansion of the cell contents. But the expansion of a turgid cell is caused by free water forcing itself into the cell against the pressure of both wall and protoplasm The water enters the cell because there is more free water outside the cell than inside of it. The pressure of turgidity, then, is the pressure of inflowing water, a pressure that for more than a century has been called osmotic pressure. If the expansive force exerted in the interior of an automobile tire when we force air into it can legitimately be called a "suction force," then also we can call the expansive force of a cell when water is forcing its way into the cell a "suction force." This reduces the idea almost to absurdity, and it seems preferable at present to refer to the pressure in cells as the "effective osmotic pressure," rather than as "suction force."

The effective osmotic pressure of root cells ranges usually from 3 or 4 to 10 or 12 atmospheres. Hannig (10) estimated the average osmotic pressure of the root cells of 62 species of plants at about 8 atmospheres. The effective pressure is nearly always less than the osmotic concentration indicates, for the protoplasm is not completely semipermeable, and there is some wall pressure in turgid cells.

The saturation deficit is ordinarily not very large in roots, but it may become considerable with high transpiration. Kennedy and Crafts (13) have demonstrated quite noticeable deficits in the underground roots and stems of the bind weed (*Convolvulus* sp.) They found these deficits sufficient to pull poisonous solutions deep into the underground organs when applied to the cut ends of the vines after heavy transpiration. If Renner's (23) studies of the reduction of the vapor pressure of plasmolyzed cells can be applied to root cells, the saturation deficit of the root colloids would be very small in the presence of effective osmotic pressures of 6 to 8 atmospheres. Colloidal imbibition forces equal to this in magnitude would not need to produce a vapor pressure decrease of much more than 0.5%, to be in equilibrium with the osmotic pressure of the cell vacuoles.

The causes of the osmotic pressure in living cells are not simple, and any force which leads to the intake and retention of water by a cell is a component in the production of osmotic pressure. The largest factor in pressure development is the unequal distribution of free water outside and inside the cell, and the diffusion of water molecules from places of high free-water content to places of lower free-water content. In addition, there are colloidal hydration forces and molecular and ionic surface attractions which are effective factors in the intake of water and in the limiting of diffusion to a unidirectional path. Still another factor in determining the osmotic pressure in the cell is the electrical condition of the porous membrane, and of the solutions involved. Loeb (15) has pointed out the influence of electroendosmose in the passage of water through tissues, and Bartell (2) has thrown important light on the electrical control of diosmotic action. Electroendosmose may increase the pressure in the cell, or it may reduce osmotic pressure by causing migration of water in a direction opposite to what one would expect from the concentration conditions of the cell. The important fact to remember is that osmotic pressure is complex, and that any force whatsoever, physical, chemical, colloidal, or electrical, that causes absorption and retention of water by the cell is in part responsible for the osmotic conditions of that cell.

The actual absorption of water from the soil occurs in the colloidal membranes that delimit the epidermal cells. For a long time we have held that root hairs are the main organs of absorption. Their structure indicates an important function. They multiply the root surfaces enormously, from 25 to 30 times in the seedlings of radish and mustard grown in moist air. The root hair walls are thought to be made mainly of pectic materials (12, 24) which are capable of great hydration and should serve admirably for the imbibitional removal of water from the soil films. They are so intimately joined to the mineral soil particles that one can hardly escape the conviction that these hairs are the main absorbing organs of the plant. That water traverses such materials readily must be granted. Reed and Bartholomew (22) have recently ascribed to the middle lamella of the cell, constructed of the same kind of material, a rôle in the transportation of water through the tissues of fruits.

In the hydration of colloidal surfaces it is possible that some orientation of the water molecules occurs in the surface. While we usually think of such oriented layers as monomolecular, yet there is some evidence favorable to the existence of films of water on solids like glass of more than monomolecular dimensions. The existence of oriented layers of water molecules on colloidal surfaces has not been proved, but it is possible that we have orientation of water on root hair surfaces and on the surfaces of colloidal gels on soil particles. Root hairs and soil particles are so intimately connected that there is a possibility of orientation of the entire interfacial water mass. Such a condition might affect the solubility of soil minerals, the rate of absorption of salts, and the rate of intake of water from the soil solution.

While we have almost universally accepted the point of view that the root hairs are the main absorptive organs of the root, this view has been sharply challenged by St. Popesco (25) who claims that the main absorptive region of the root lies below the root hairs, in the region of differentiation and elongation of the cells which later mature into vascular elements. We should not go to the extremity of denying the existence of absorptive functions on the part of root hairs. Close observation of the soil-root water relations in relatively dry soils will convince one that the root hairs do absorb water. But we may have exaggerated their importance because they seem so obviously fitted for their function.

With the root hairs and elongating root regions in intimate contact with the soil particles and soil colloids, the water conditions of the soil become vitally important to the whole absorption problem.

The maximum quantity of available water which a soil may hold for the plant is determined by the difference between the moisture capacity of the soil and the wilting coefficient as defined by Briggs and Shantz (5). In the case of xerophytic plants, the film water represented by the difference between the wilting coefficient and the hygroscopic coefficient may be available for maintenance of life, as Alway (1) has shown. Mesophytic plants, however, do not secure water rapidly enough to prevent desiccation in soils with a moisture content below the wilting coefficient.

In the range of capillary moisture between the maximum capacity and the optimum water content of the soil, the rate of water absorption by the plant will be determined by the internal imbibitional and osmotic conditions of the root cells. Free water exists in the soil beyond the capacity of the plant to absorb it. But as the soil moisture drops below the optimum content for plant growth, the water-holding forces of the soil begin to retard intake, and the rate of intake now becomes a function of the external environment. The plant would now absorb water more rapidly if more free water were present.

The forces with which the soil holds water at different moisture contents between air-dry and the wilting coefficient were first measured by Shull (27) who used seed colloids surrounded by semi-permeable membranes for these determinations. The method has been recognized as the most accurate yet available for making such measurements (18). The results of these studies indicated that an air-dry soil holds its hygroscopic water with a force of 900 to 1,000 atmospheres. As the film water increases, the forces resident upon the surfaces of the soil particles and soil colloids decrease, until at the wilting coefficient the water is held by a force of about 4 atmospheres. The rate of decrease of the water-holding forces of the soil with increasing water content depends upon the type of soil used. In a heavy silt loam like the Oswego sub-soil, addition of 3 5% of water above the air-dry content reduced the surface water-holding power of the soil from nearly 1,000 atmospheres to 375 atmospheres, and a 6% addition of water to the dry soil reduced the surface forces to about 130 atmospheres.

The wilting coefficient of this soil was about 13.3%, and addition of enough water to bring it to the wilting coefficient brought the surface forces to about 4 atmospheres. The same water-holding power at the wilting coefficient was found for a number of different types of soils. The method of incorporating the water into the soils in these investigations was found later not to be quite satisfactory, and the method of allowing thin layers of soil to absorb moisture from a saturated atmosphere for different lengths of time was adopted. Using this improved method of incorporating soil moisture, Wolfe (36) has remeasured the water-holding power of soils across the hygroscopic range from air-dry to the hygroscopic coefficient. The general results are in complete agreement with the original studies, but the measurements are more accurate. His determination of the surface forces of soils at the hygroscopic coefficient is particularly valuable, as the earlier results had indicated a value much too large. The curves plotted by Shull indicated a value of about 75 atmospheres, whereas in Wolfe's studies he shows that the true value for this equilibrium point of the soil-particle-water vapor system is constantly about 25 atmospheres for different types of soils. My own experience with other soils indicates that the values given by Wolfe are approximately correct. These determinations give a concrete picture of the soil moisture conditions which help to determine the absorption rate of the root cells.

At the time that the plant wilts, the soil is holding water with a force about half as great as the osmotic pressure equivalent of the root sap concentration. The figures of Hannig would need practically no correction for wall pressure in Ursprung's sense, at the time of wilting. The fact that absorption by the root becomes too slow at this point to maintain turgidity is undoubtedly related to the static condition of water in the thin films that prevail in relatively dry soils. It is this fact which makes the wilting coefficient a definite soil moisture content for each type of soil. While Caldwell (6) and Shive and Livingston (26) emphasized the idea that evaporation intensity might affect the value of the wilting coefficient; yet, when the soil point method of measuring water-supplying power was developed (14), measurements made on various soils at the wilting coefficient indicated that the water-supplying power was constant for all soils at that point. It is my conviction that the wilting coefficient represents a fairly definite water condition in the soil in which capillary movement, and possibly root extension also, have been reduced to a point too low to renew the water lost by transpiration.

Formerly, capillary forces in soils were assumed to transfer water rapidly from place to place, and particularly to transfer moisture from the water table toward the plant root Capillarity was supposed to cause a flow of water toward the absorbing root cells from all directions This may happen at certain levels of moisture content in the soils, but it has become clear from observations by many investigators that capillary movement is less than has been assumed, and that the main movement of water in soils is downward, in response to gravity Recently, Veihmeyer and Hendrickson (34) have measured the capillary transfer of water quantitatively and find it very slight. In a soil with 22% of water (maximum field capacity) in contact above and below with soil masses containing 14.5% of moisture, the transfer of water upward and downward amounted to about 8 inches in 139 days. The situation may be different with soil masses that have not undergone structural changes from handling, but capillarity is probably less of a factor than has been assumed with respect to the supply of water to the root surfaces.

If capillarity is less important in this regard, the extension of the root system into new regions of the soil becomes more important. If the water does not move to the plant, the plant must move to the water, as long as saturation deficit does not become so large as to inhibit growth and the production of root hairs.

In soils that have been exhausted of moisture by plants, it is possible to observe the local removal of water by the root hairs.

The roots of buckwheat (29), for instance, grown in soils which were kept near the wilting coefficient, had removed the water from a column of soil about 6 mm in diameter which the root had traversed during growth. The soil surrounding this column was darker in color and very evidently more moist than the soil adjacent to the root. The diameter of the drier soil column was almost exactly that of the root with its root hairs. The line of demarcation between the drier and moister soil was very sharp, which shows that capillarity had not been able to equalize the moisture conditions from beyond the reach of the root hairs. This absorption of moisture from the soil in actual contact with the root hairs must be a factor of great importance in relatively dry soils, and the extension of the root into new soil masses would be the main method of maintaining water intake. The ability of obtaining water in this way may make it possible for xerophytes to live for a considerable time in soils that are below the wilting coefficient.

While it has been shown that the cell sap of the root cells will increase in osmotic concentration as soil moisture becomes hard to obtain, this would have little effect in maintaining the intake of water by the root. When the soil environment becomes relatively dry, the lack of water negatives the influence of the increasing diffusion gradient which would be effective if water were present. Under ordinary conditions the osmotic gradient for absorption is probably from 4 to 6 atmospheres.

In conclusion, something may be said of the soil point method of determining the availability of water in the soil. The porous porcelain soil point gives promise of being a valuable empirical tool. When it has been properly standardized, the readings obtainable may check closely. In one test made in a prepared soil (29), standardized soil point readings did not vary more than 0 5% from the average of the tests. In this regard they proved more valuable than the lead pencil points which have been used for such tests (11, 16).

Wilson (35) has recently made a study of the relation of soil moisture to the growth of lawn grasses and other plants, using soil points for the determination of water-supplying power of the soil. He finds that when grass has been injured by drouth, it begins to recover when the soil point reading is 100. This means that 100 mg of water are delivered to the soil point through an area of 12.5 square cm in one hour. Vigorous healthy growth occurred with soil point readings of 500 or higher.

It is obvious that one could use the soil point readings to control the watering of lawns, and general irrigation practices, in the interests of economy of water and more timely application, if the soil point were first used empirically to determine the soil moisture conditions at or just before the wilting of vegetation begins. Once we know the requirements of plants in terms of soil point readings, the soil point becomes a practical instrument in the control of soil water. However, as investigators, we must be cautious in reasoning from soil point readings to plant behavior. There are limitations to the method which must be frankly admitted. The contact between the soil point and the soil is never like that between root hair and soil. And a soil point reading made in a soil which has been exhausted of moisture by a plant root would not give a true picture of the water-supplying power of the soil. The reading from the general soil mass would be higher than that from the part which the root had traversed There are other difficulties in very dry soils which make soil point readings unsatisfactory, but in moist soils they give results which seem to me reliable and trustworthy.

The absorption of water, then, involves the surface and colloidal forces of both root and soil, and the osmotic properties of root cells. Water travels with great power from the regions of higher free water to regions of less free water. The unidirectional path in the root is a consequence of the limitations set upon the outward diffusion of water by the physical and chemical forces of the colloidal substances and vacuoles of the living plant cells While osmotic action has usually been considered the main factor in absorption by roots, imbibitional forces play a very considerable rôle, and it requires both imbibition and osmotic forces to account satisfactorily for the entry of water into the permeable root regions of the plant.

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CHEMICAL SEED TREATMENTS FOR SORGHUMS[1]

A. F. SWANSON and R. E. GETTY[2]

The sorghums, because of their superior drought resistance, are of growing importance in the southern part of the Great Plains area where corn often is unreliable. The irregular stand caused by poor germination, however, is often a limiting factor in obtaining optimum yields of sorghum.

Several factors are responsible for poor germination, some environmental, others inherent in the seed itself. Low temperatures and a cold wet seedbed are almost certain to reduce the germination of most varieties, and may cause almost complete failure of some. A seedbed which is hard, dry, or otherwise in poor tilth also creates a risk of irregular germination and uneven crop growth, although a fair stand may result if rains follow planting.

Sorghum varieties differ in their ability to withstand the effects of a period unfavorable for germination under field conditions This difference may be due in part to the seed coat structure. If the seed coats of feterita, hegari, and kaoliang are examined under the microscope, there is revealed a thick starchy layer, the mesocarp, measuring from 70 to 80 microns in thickness. In the seeds of kafir and milo the thickness of this layer is from 35 to 45 microns, while in Red Amber sorgo and broomcorn it is only about 10 microns. The degree of thickness of the starchy mesoderm seems to have some relationship to the rate at which sorghum seeds can absorb water, as feterita absorbs about 45% more water in a two-hour period than does either Red Amber sorgo or Blackhull kafir. The hypodermal and epidermal layers of the pericarp, lying directly above the mesoderm, differ in thickness, texture, and luster in different sorghums. Those of feterita are thin and chalky and about 15 microns in thickness, while those of kafir, milo, and many of the sorgos are hard and glossy, and approximately 45 microns in thickness.

It has been noted repeatedly under field conditions that sorghums like feteritas, hegari, and kaoliangs often germinate with difficulty when cold wet weather immediately follows seeding, that somewhat less difficulty is experienced with the kafirs and milos, whereas Red

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Amber sorgo and broomcorn often volunteer freely from shattered seed which has been subject to varied conditions of moisture and temperature throughout the winter and spring. It seems, therefore, that texture of the outer layers of the pericarp, the thickness of starchy mesoderm, and the relationship of these to the rapidity with which the seed takes up moisture rank with soil temperatures at seeding time as important germination factors, along with seed-borne or soil organisms to which the seed may become host.

EFFECT OF CHEMICAL TREATMENTS ON GERMINATION AND STAND

In recent years many disinfectants and fungicidal compounds appearing on the market have been claimed by their manufacturers to stimulate germination, and in some cases early plant growth also. Therefore, in 1927, experiments were begun at the Ft. Hays Branch Experiment Station, Hays, Kans., to study the effect of chemical treatments on the germination of Red Amber sorgo, Dawn kafir, and feterita. Red Amber sorgo was selected as a sorghum with strong germinating potency, Dawn kafir as of medium germinating vigor, and feterita as weak in this respect. Feterita is of special interest because the acreage in Kansas has declined from 265,322 acres in 1915 to 45,629 acres in 1926. The difficulties farmers have had in getting stands appear to account for the great decrease in acreage.

The four commercial chemicals used were Coppercarb, Bayer dust, Semesan, and Uspulun. The first two of these are dusts and were applied at the rate of 4 ounces to the bushel. The last two were used in liquid form, 1 part of the powder dissolved in 400 parts of water by weight, and the seed soaked one hour. The names of the brands listed above and in Tables 1 and 2 are furnished merely as information and no recommendation of the use of one as compared with another is hereby made. One hundred seeds of each of the three varieties, Red Amber sorgo, Dawn kafir, and feterita, were sown at weekly intervals for eight weeks in 1927, and for seven weeks in 1928, in a seedbed of excellent tilth Various degrees of difficulty were experienced with cold and wet weather during the period. A summary of the stands obtained in the two-year period, 1927–28, is shown in Table 1.

The harder seeds, those of Red Amber sorgo and of Dawn kafir, responded very little to treatment in 1927, but some benefit was shown in 1928. Feterita was helped decidedly in both seasons. It was concluded that when sound seed of other than soft-seeded sorghums is sown, seed treatment is not necessary to a good stand under

TABLE 1.—*Summary of percentage stands obtained from Red Amber sorgo, Dawn kafir, and feterita after various chemical treatments of the seed. Ft. Hays Experiment Station, Hays, Kans., in the two-year period, 1927–28.*

Month of planting	Number of plants from 100 seeds treated by by method indicated below Copper-carb	Check, none	Bayer dust	Semesan	Check, none*	Uspulun
Red Amber sorgo, F.P.I. No. 17548						
Av. 4 April plantings, 1927	40	42	45	46	52	46
Av. 2 April plantings, 1928	65	52	61	71	53	76
Weighted av., April plantings	48	45	50	54	52	56
Av. 4 May plantings, 1927	77	81	80	78	79	77
Av. 5 May plantings, 1928	76	72	77	83	70	77
Weighted av., May plantings	76	76	78	81	74	77
Dawn kafir, H. C. No. 2421						
Av. 4 April plantings, 1927	43	44	43	43	49	42
Av. 2 April plantings, 1928	61	43	46	56	49	69
Weighted av., April plantings	49	44	44	47	49	51
Av. 4 May plantings, 1927	66	68	70	70	67	70
Av. 5 May plantings, 1928	64	65	61	68	55	70
Weighted av., May plantings	65	66	65	69	60	70
Feterita†						
Av. 4 April plantings, 1927	31	16	33	32	17	30
Av. 2 April plantings, 1928	23	19	14	32	12	29
Weighted av., April plantings	28	17	27	32	15	30
Av. 4 May plantings, 1927	51	42	57	59	33	53
Av. 5 May plantings, 1928	43	31	34	44	34	46
Weighted av., May plantings	47	36	44	51	34	49
Weighted average 3 varieties; or total of 45 trials 1927-28	54.3	49.8	53.6	57.9	49.1	57.4

*In 1927, soaked in tap water one hour.

†Feterita C. I. No. 182 1 used in 1927, and Dwarf feterita F. C. No. 9076 in 1928.

favorable conditions. As there always is risk of cold wet weather following seeding and as treatment with these compounds prevents kernel smut, the use of a chemical treatment may well be advisable.

No stimulation of vegetative vigor was noted in the seedlings from the treated seed over that of the seedlings from the untreated seed at the time of emergence or thereafter.

EFFECT OF CHEMICAL TREATMENTS ON STAND AND YIELD OF FETERITA UNDER FIELD CONDITIONS[3]

This experiment supplements the nursery tests by using plats large enough to obtain comparable yields. Well-cleaned, machine-threshed seed of good quality was used. It would average better than seed from most farms. The seedings were made on three differ-

[3] This experiment was outlined in 1926 by H. N. Vinall, Senior Agronomist, Office of Forage Crops, Bureau of Plant Industry, U. S. Dept. of Agriculture, and work under the outline began at Chillicothe, Tex., and Hays, Kans., that year. Soil conditions at Hays in the spring of 1926 were so dry that uniformly poor stands were obtained and no records were kept of the results.

ent dates under favorable soil conditions in both years. The rate of seeding was in excess of what would have made a desirable stand had each seed germinated and produced a plant. Counts were made of the final stand, produced without thinning, and recorded in terms of row space per plant in inches. This information, with yields in tons and bushels per acre, is shown in Table 2.

TABLE 2.—*Average effect of different chemical treatments on the stand and yield of Dwarf feterita sown on three dates at Hays, Kans., in each of the two years, 1927 and 1928.*

	Row space per plant, inches*			Yield per acre*					
				Air-dry forage, tons			Grain, bushels		
Treatment	1927	1928	Aver.	1927	1928	Aver.	1927	1928	Aver.
Coppercarb......	7.9	13.1	10.5	3.26	2.79	3.03	37.5	35.4	36.5
Bayer Dust	8.4	21.2	14.8	3.27	2.45	2.86	39.3	30.7	35.0
Check, none.	8.2	25.4	16.8	3.22	2.39	2.81	36.6	31.0	33.8
Semesan	7.9	11.6	9.8	3.13	3.15	3.14	34.7	42.5	38.6
Uspulun .	8.3	11.6	10.0	3.16	3.14	3.15	33.6	41.2	37.4

*Average of three dates.

The two-year average yields of both forage and grain, as shown in Table 2, vary almost in direct ratio with the percentage of germination, or inversely with the row space per plant. The variations in yield seem to be due almost wholly to differences in stand. No added vigor was observed in the seedlings from the treated seed when compared with that from the untreated seed. Similar experiments with barley and corn have given no indication of increased plant vigor due directly to seed treatment. The increased yield obtained from the treatment of feterita with chemical compounds was largely due to a greater number of plants per acre than when untreated seed was used.

NOTE

A HAND CLOVER HULLER

The breeding work in red clover in the Agronomy Department at Purdue Agricultural Experiment Station has been greatly handicapped by the lack of a device which is suitable for hulling small numbers of plants. Hulling is a very unpleasant task when attempted by hand. The hands soon become sore, with the result that only a small portion of seed is rubbed out. Various hand devices have been used by the writer, but none have met this need so well as a small hand-driven machine which has been recently constructed.

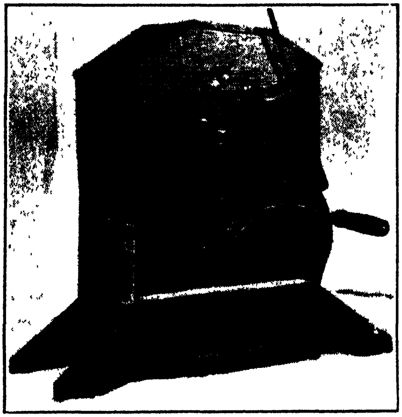

FIG. 1.—Side view showing the approximate size and shape of the machine, the crank, and the lever which operates the galvanized crescent-shaped frame to which the apron is attached.

This machine was designed and built by F. N. Jones of Lafayette, in cooperation with the writer. It operates by hand and seems capable of being used to hull small lots of alsike and white or dutch and other clovers equally as well as red clover.

The huller consists of three main parts, *viz.*, the cylinder and concave; a wooden drum about 8 inches in diameter covered with coarse tapestry with the warp and woof side exposed; and an adjustable apron made of the same material.

The apron is secured to a crescent-shaped galvanized iron frame so shaped in order that it will fit closely to the surface of the drum. The frame in turn is fastened or hinged at the upper end at a point just below and to one side of the concave. The frame is attached to a lever. (See Fig. 1.) With the lower end of the frame free to move, it can be moved back and forth by the lever.

The ends of the tapestry apron are fixed to the upper and lower ends of the galvanized

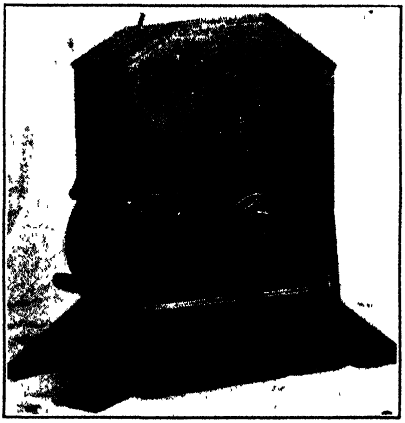

FIG. 2.—Side view showing the pulley on the drum shaft which drives the cylinder.

frame and by means of the lever the apron is held in its proper position for hulling.

A crank (Fig. 1) on the end of the cylinder shaft operates the drum, and a small pulley attached to the opposite end drives the cylinder (Fig. 2).

The essential parts of the machine are the drum and the adjustable apron. This is the hulling mechanism The drum revolves, but the apron is stationary and by means of the crescent-shaped galvanized iron frame, adjusted by means of a lever, the apron can be made to hug closely to the drum. This brings together two rough harsh surfaces of tapestry. The rubbing surface thus afforded consists of some 10 to 12 inches and provides very favorable conditions for hulling, with no breaking or cracking of the seed.

The clover heads when dry are fed into the cylinder at the top. They are immediately broken and torn apart and fall between the apron and drum which lie immediately below the cylinder. The clover then passes between the rough surfaces of the tapestry, held tightly together by means of the lever, and the hulls are completely rubbed off and ground to a fine dust. Hulls and seed then fall into a small box below and are ready to be separated.

This machine does not have a cleaning device. In practice, it is found that satisfactory separations can be made with the model clipper mill or by means of a blast from an electric fan.—G. H. Cutler, *Department of Agronomy, Purdue University, Lafayette, Indiana.*

BOOK REVIEW

A TEXT-BOOK OF TROPICAL AGRICULTURE

By Sir Henry Alford Nicholls, revised by John Henry Holland. New York: Macmillan Co. XXXVI+639 pages, illus. Ed. 2. 1929. $5.

The first edition of this book, written in 1892, was the successful manuscript submitted in a competition sponsored by the Jamaica Government for the best "Text-Book of Tropical Agriculture." The present volume is an attempt to revise and bring up to date the subject matter in a field in which very great advances have been made during the last 40 years. Part I, comprising the first 105 pages, is devoted to the "Elements of Agriculture." The treatment is elementary indeed. Part II deals with "Agricultural Products." Coffee, cacao, tea, sugar cane, and tobacco are treated in separate chapters; the other tropical crops are grouped under such headings as fruits, spices, drugs, etc.

It would appear doubtful whether the labors of revision of a work as old as Nicholls' original book are justified. The present reviewer has first-hand knowledge of only a few of the crops discussed in the book. The accounts of sugar cane and pineapples are quite inadequate and, in some particulars, misleading. It is stated, for example, that lime is advantageous in pineapple growing, whereas all our experience in Hawaii, where we produce 300,000 tons per year, would indicate that it is an unusually bad thing. One gathers that the authors consider 3 tons of sugar per acre as an exceptionally good yield; in Hawaii it would be considered a very poor one. One Hawaiian plantation producing over 70,000 tons of sugar averaged 12 tons per acre in the 1928 season. It would seem that an account of how such yields are obtained would be more instructive than descriptions of relatively primitive West Indian practices.

As a source of very general information on a wide range of tropical crops, the book might prove useful. As an account, either of the general principles of modern agriculture or of present-day developments in the tropics, it leaves much to be desired. (A. L. D.)

AGRONOMIC AFFAIRS

MEETING OF CORN BELT SECTION

The summer meeting of the Corn Belt Section of the American Society of Agronomy will be held at Lincoln, Nebraska, on June 23 and 24. Registration will be at 9 A. M. Tuesday, in the Students Activities Building, at the Agricultural College campus. The two-day session will be devoted largely to an inspection of the Crops and Soils work of the Experiment Station. The Substation at North Platte, Nebraska, extends the visitors an invitation to inspect their experimental work following the meetings at Lincoln.

NEWS ITEMS

PROFESSOR F. D KEIM has been appointed Associate Chairman of the Department of Agronomy of the University of Nebraska and will have charge of the instructional work of the Department and some of the executive details. Dean W. W. Burr retains the chairmanship of the Department.

RALPH S BRISTOL on April 15 succeeded J D. Remsberg as Extension Agronomist at the Idaho College of Agriculture Mr. Remsberg is now in charge of research for the Chipman Chemical Engineering Company at Bound Brook, N. J.

W. H. DAUGHTERY, County Agent of Dinwiddie County, Virginia, who is at present doing graduate work at Michigan State College, has been appointed Assistant Extension Agronomist in the Virginia Agricultural Extension Division to succeed S D. Preston who resigned to do educational and demonstrational work for the American Cyanamid Company. The appointment is effective July 1.

THE Virginia Agricultural Experiment Station has appropriated funds for establishing a sub-station in the bluegrass section of southwestern Virginia to be devoted entirely to problems of pasture improvement. W. R Perkins, field agent for the Virginia Crop Improvement Association, has been appointed Superintendent of this sub-station

THE Virginia State legislature has appropriated a special fund of $7,500 a year for two years for initiating soil survey work in the state, effective July 1, 1930. The Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, will match this appropriation making $15,000 available annually for initiating this work.

MAX A. MCCALL, for the last six years assistant head of the Office of Cereal Crops and Diseases in the Bureau of Plant Industry, U. S. Dept. of Agriculture, has been named principal agronomist, in charge of this office. Mr. McCall has been acting in charge of the office for the last three months.

DR. J. ARTHUR HARRIS, for several years head of the Department of Botany of the University of Minnesota, died recently following an operation for appendicitis in a Minneapolis hospital. Dr. Harris in recent years was a familiar figure at the meetings of the American Society of Agronomy and offered much constructive criticism of agronomic research in occasional contributions to this JOURNAL and elsewhere.

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THE PHOSPHORUS CONTENT OF THE SOIL SOLUTION AND ITS RELATION TO PLANT GROWTH[1]

J. W. TIDMORE[2]

Recent studies have shown that corn will make good growth in soils whose displaced solutions contain only small amounts of phosphate. Other studies have shown that corn will make good, but not optimum, growth in culture solutions whose phosphate concentration is only 0.25 p. p. m. PO_4. Those studies, however, have not proved that corn will make a satisfactory growth in culture solutions whose phosphate concentration is as low as that of some rather productive soils. It is essential that it be definitely established whether plants will grow in culture solutions of as low a PO_4 concentration as in displaced soil solutions of productive soils. If it is proved that plants will not grow in culture solutions of as low a PO_4 concentration as is found in some productive soils, it will indicate a difference in the absorptive process in the two media or that the displaced solution is not the true soil solution from which the plant absorbs all of its nutrients. The establishment of such a fact would, therefore, result in some doubt as to the value or interpretation of past work on the displaced soil solution and on the value of the culture solution method for studying problems of plant nutrition involving the soil-plant relationship.

This paper will deal briefly with (a) the minimum phosphate concentration for maximum plant growth in culture solutions, (b) plant growth in soils whose displaced solutions contain only small amounts of phosphate, and (c) the inadequacy of the phosphate in the displaced soil solution for plant growth.

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[1] Contribution from the Soils Laboratory, Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Paper read as part of the symposium on "Phosphorus" at the meeting of the Society held in Chicago, November 14, 1929. Published with the approval of the Director.

[2] Associate Professor of Agronomy.

MINIMUM PHOSPHATE CONCENTRATION FOR MAXIMUM PLANT GROWTH IN CULTURE SOLUTION

Considerable work has been done during the past few years concerning the minimum concentration of phosphate required for maximum growth of plants in solution cultures. Hoagland and Martin (3)[3] grew barley in culture solutions of different phosphate concentrations, the lowest being 0.7 p.p.m. They obtained a satisfactory growth at that concentration and in a second experiment maximum growth was secured at a phosphate concentration of 1.1 p.p.m. Parker (6) found that the maximum growth of corn and soybeans was obtained in culture solutions having a phosphate concentration of 0.5 p.p.m. PO_4 Subsequently, Parker and Pierre (7) obtained a maximum growth of corn at a phosphate concentration of 0.25 p.p.m. PO_4. They expressed the opinion that a very good growth could be secured with a phosphate concentration of 0.1 p.p.m. if that concentration could be actually maintained.

In the culture solution experiments mentioned above, the phosphate concentrations were not adequately maintained. The quantity of the culture solution used per culture was entirely too small for the number of plants grown in it. Hoagland and Martin (3) used 4-liter containers for one plant, while Parker and Pierre (7) used 100-liter vessels for three plants. They state that with these volumes the PO_4 concentration was not adequately maintained.

It seemed desirable, therefore, to make a further study of plant growth in culture solutions of varying phosphate concentrations.

EXPERIMENTAL PROCEDURE

The procedure used in the following experiment differed from the usual solution culture experiments in that a special effort was made to maintain the PO_4 content of the solution constant The PO_4 concentrations to be maintained in the various cultures were 0.05, 0.1, 0.2, and 0.5 p.p.m. In order to maintain a constant concentration, each plant was grown in a large volume of solution and the PO_4 content of the solution was renewed from one to three times a day. Nine plants were grown in each culture vessel having a capacity of 1,000 liters, thus affording 111 liters per plant. In order to renew continually the solution about the plant roots, the solution was thoroughly stirred by bubbling a strong stream of air through it. This also served to aerate the cultures thoroughly.

Corn, sorghum, and tomato seeds were germinated in quartz sand and transferred at the age of one week to the culture solutions containing different phosphate concentrations. Three seedlings of each crop were placed in each culture solution. All treatments were in duplicate.

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[3] Reference by number is to "Literature Cited," p. 488.

PLANT GROWTH

The dry weights of the plants are recorded in Table 1. It is noticed that corn made very little growth in the culture solution containing 0.05 p.p.m. PO_4, the dry weight of the tops being only 4.1 grams. The corn tops grown at 0.1 p.p.m. PO_4 made about 35 times as much growth as those grown at 0.05 p.p.m., while the roots were about 15 times as heavy as those grown at the lowest PO_4 concentration. The weights of the tops of six corn plants grown in culture solutions with 0.1, 0.2, and 0.5 p.p.m. PO_4 were 140.6, 802.9, and 1,125.8 grams, respectively.

TABLE 1.—*Dry weight in grams of plants grown in culture solutions of the phosphate content indicated.*

PO_4 in p.p.m.	Tops	Roots	Total
	Corn, 6 plants		
0.05	4.1	3.1	7.2
0.10	140.6	45.7	186.3
0.20	802.9	98.6	901.5
0.50	1,125.8	136.8	1,262.6
High PO_4 soil	204.1	123.0	327.1
Low PO_4 soil	174.6	51.0	225.6
	Sorghum, 2 plants		
0.05	—*	0.3	—*
0.10	28.2	14.7	42.9
0.20	61.4	18.1	79.5
0.50	99.1	14.5	113.6
High PO_4 soil	65.6	13.3	78.9
Low PO_4 soil	32.3	7.2	39.5
	Tomatoes, 3 plants		
0.05	—*	0.3	—*
0.10	34.8	19.1	53.9
0.20	53.6	20.8	74.4
0.50	126.0	45.8	172.8
High PO_4 soil	—	—	—
Low PO_4 soil	—	—	—

*Not determined.

Table 1 also shows that sorghum made a very poor growth in culture solutions having very low PO_4 concentrations. The dry weights of the plants grown at 0.05 p.p.m. PO_4 were not obtained, because these plants were used in other studies. The growth, however, at this concentration was practically nothing. The dry weights of the tops of two sorghum plants were 28.2, 61.4, and 99.1 grams grown in culture solutions with 0.1, 0.2, and 0.5 p.p.m. PO_4, respectively.

The dry weights of tomato plants, as indicated in Table 1, increased with the PO_4 concentration of the culture solution. There was practically no growth at 0.05 p.p.m. PO_4, though the weights were not obtained. The dry weights of the tops of three tomato plants were 34.8, 53.6, and 120.0 grams when grown in culture solutions with 0.1, 0.2, and 0.5 p.p.m. PO_4, respectively.

The data show that a concentration of at least 0.5 p.p.m. PO_4 is required for the maximum growth of the three different plants and that very little growth is made at 0.05 p.p m. The top-root ratio increased with the phosphate concentration of the culture solution. In other words, there was a greater root growth in proportion to the top growth in the solutions with low phosphate concentrations. This statement holds for the three crops.

PLANT GROWTH IN SOILS HAVING SMALL AMOUNTS OF SOLUBLE PHOSPHATE

Many soils have been reported whose soil solutions contain extremely small amounts of phosphate, yet these soils produce excellent crops. The phosphate concentration in soil solutions from different soils usually varies from a trace to 10 or 12 p.p.m. Burd and Martin (1) determined the phosphorus content of the displaced solution of several California soils. The total PO_4 content varied from 1.1 to 12.5 p.p.m. The phosphate concentrations of these soil solutions are considered high and excellent plant growth would be expected so far as PO_4 is concerned.

Pierre and Parker (8) found that the inorganic PO_4 content of several soil solutions varied from a trace to 7.26 p p.m. In many cases, they have recorded the crop response to phosphate fertilization. A part of their work is recorded in Table 2. This table indicates that the displaced solutions of many soils contain low concentrations of inorganic PO_4 and show no response to phosphate fertilization for certain crops. The displaced solutions of the soils which show no response to phosphate contain as an average 0.12 p.p.m. inorganic PO_4. This figure would be 0.06 p.p.m. if soils Nos. 9 and 20 were omitted from the average. Several of the displaced solutions contain approximately 0.04 p.p.m. PO_4. Some of these soils respond to phosphate fertilization, while others give no response. Corn, sorghum, and tomatoes would probably not make any growth in culture solutions if the PO_4 concentration was not greater than that of most of the displaced solutions mentioned in Table 2.

Corn and sorghum were grown in soil cultures at the same time as the above plants in the solution cultures. These soil cultures were to compare the growth obtained in soil cultures containing high and low phosphate with the growth in culture solutions.

A soil with a displaced soil solution very low in phosphate was placed in 4-gallon earthenware pots. All of the pots were fertilized with potassium chloride and sodium nitrate at the rate of 100 and 800 pounds per acre, respectively. Half of these pots were fertilized with superphosphate (1,000 pounds per acre) and are designated as high phosphate cultures. The other half of the pots received no phosphatic fertilizer and are designated as low phosphate cultures.

TABLE 2.—*Data on the displaced solution of the soils indicated.*

Soil No.	Soil type	Crop response to phosphate fertilization	Displaced solution	
			Inorganic PO_4 in p.p.m.	Organic PO_4 in p.p.m.
2	Norfolk sandy loam	None	0.14	0.54
9	Silt loam	None	0.30	0.43
13	Hampstead silt loam	None	Trace*	0.51
15	Maury silt loam	None	0.08	0.56
16	Miami silt loam	None	7.26†	—
17	Colby silt loam	None	0.03	0.26
18	Colby silt loam	None	0.03	0.37
19	Grundy silt loam	None	0.04	0.68
20	Gray silt loam	None	0.35	0.89
Average		None	0.12	0.53
1	Greenville sandy loam	Slight	0.03	0.23
21	Gray silt loam	Slight	0.20	0.18
10	Tifton sandy loam	Medium	0.32	0.60
14	Webster silty clay	Medium	0.04	0.88
3	Orangeburg sand	Good	0.02	0.28
4	Ruston sand	Good	Trace	0.38
8	Decatur silt loam	Good	0.05	0.15
5	Cecil clay loam	Unknown	Trace	0.42
6	Portsmouth sandy loam	Unknown	Trace	0.24
7	Norfolk sandy loam	Unknown	0.04	0.60
11	Cecil sandy loam	Unknown	0.06	0.90
12	Lintonia fine sandy loam	Unknown	Trace	0.30
Average			0.09	0.47

*Trace recorded when less than 0.02 p.p.m.

†Figure for total phosphorus, not included in average.

The displaced soil solution of the low PO_4 soil cultures contained approximately 0.03 p.p.m. inorganic PO_4 and produced a better growth of corn than the culture solutions containing 0.1 p.p.m. PO_4. The growth of sorghum was approximately the same in the low phosphate soil cultures as in culture solutions which contained 0.1 p.p.m. Corn and sorghum grew better in the high PO_4 soil cultures than in the culture solutions at 0.1 p.p.m.

Several soils have been studied whose displaced soil solutions contain extremely small amounts of PO_4, yet excellent crops are produced. For example, the displaced soil solution from plat 2 of the Cullars rotation of the Alabama Experiment Station contains about 0.03 p.p.m. inorganic PO_4 and this area produces 42 bushels of corn per acre. The unfertilized plat of the Aledo, Illinois, experimental field has an average corn yield of approximately 55 bushels per acre. The displaced soil solution from this plat contains only 0.04 p.p.m. inorganic PO_4. Plants in these soils in all probability have access to a greater phosphate concentration than is found in the displaced solution.

Some studies are in progress at the Alabama Experiment Station to determine whether or not the PO_4 concentration of the displaced soil solution is constant. This study indicates that the PO_4 concentration is not constant, but in the case of the low phosphate soils the displaced soil solution never contains PO_4 in sufficient concentrations to produce good plant growth.

INADEQUACY FOR PLANT GROWTH OF PHOSPHATE IN DISPLACED SOIL SOLUTION

The culture solution experiment which has been presented, and others, indicate that corn, sorghum, and tomatoes will not make a satisfactory growth in culture solutions containing less than 0.1 p.p.m. PO_4. It is also known that plants will make an excellent growth in a soil whose displaced solution contains only a trace of inorganic PO_4. There is no apparent reason for assuming that plants will grow at a lower concentration of PO_4 in the soil than in culture solutions. Plants in these low phosphate soils in all probability have access to a greater phosphate concentration than is found in the displaced solution. This would mean that the displaced solution is not the true soil solution. It would seem that the solid phase of the soil has an important function in the phosphorus nutrition of plants.

SOIL-ROOT CONTACT

It is apparent from the above that the root-soil contact is essential for good plant growth in some soils. Comber (2), Parker (6), Hoagland (4), and Truog (9) have discussed this phase of the subject in detail. It will not be discussed here other than to emphasize the fact that it is essential, if we are to account for the absorption of phosphate from many soils of the humid region.

CARBON DIOXIDE

Parker (5) has reported experiments which might indicate that the CO_2 given off by the plant roots did not influence the absorption of phosphate as well as other materials. In this work, however, the

CO_2 may have its solvent effect before it was drawn from the soil culture. Water which is saturated with CO_2 will not dissolve enough phosphate from the solid phase to make good plant growth in the case of many soils. This solvent has a pH value of 3.9. It may be possible that the CO_2, which is given off by the plant root immediately against a soil particle, may greatly increase the acidity at this point. If the reaction at this point can for an instant be brought down to pH 4.0 and to pH 3.0, $AlPO_4$ and $FePO_4$ will be readily brought into solution.

ROOT GROWTH

Some emphasis may be placed on the fact that a greater root development is obtained in a soil whose displaced solution has a low phosphate concentration than in a culture solution having a correspondingly low phosphate concentration. It may not be out of order to ask, why did the plant develop such an extensive root system in this soil? Plants develop excellent root systems in culture solutions containing 0.1 p.p.m. PO_4 or more.

PLANT DIFFERENCES

Some plants may absorb more calcium than others, which would lower or tend to lower the concentration of calcium in the soil solutions. If this is true where changes in H-ion concentration do not intervene to overcome the effect, phosphate concentrations should increase, as pointed out by Hoagland (4). This would mean that plants having the greater ability to remove calcium from the soil solution should have an opportunity to absorb phosphate from a solution with a higher concentration of this ion.

HIGH PHOSPHATE CONCENTRATION AROUND SOIL PARTICLE

Several years ago Parker (6) suggested that in all probability there was a higher concentration of nutrients around the soil particle than in the main body of the soil solution. This may be due to at least two things, *viz.*, to a concentration gradient as the result of solubility and diffusion processes and to adsorption phenomena.

CONCLUSIONS

Corn, sorghum, and tomatoes will not make a satisfactory growth in culture solutions with a phosphate concentration less than 0.1 p.p.m. PO_4. It has been shown that the same plants will make a satisfactory growth in many soils whose displaced solution contains less than 0.05 p.p.m. PO_4. This would seem to indicate that plants growing in the soil could obtain phosphate which is not in the displaced solution. It is thought that the following points should be emphasized in this connection: (a) soil-root contact, (b) solvent action of CO_2, (c) extent of root system, (d) plant differences, and (e) a higher PO_4 concentration around the soil particle.

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EFFECT OF ASSOCIATED SOIL TREATMENTS ON THE AVAILABILITY OF APPLIED PHOSPHATES TO FIELD CROPS ON DIFFERENT SOIL TYPES[1]

George Roberts[2]

In the following tables, crop yields are given from the several soil experiment fields in Kentucky on which superphosphate and rock phosphate have been compared under various conditions.

The following data[3] are given for the soil of each field:

Pounds per 2,000,000 pounds of surface soil

Field	Total P	P soluble in N/5 HNO_3	Ca soluble in N/5 HNO_3	CaO requirement, Hopkins method	pH
Mayfield	960	11	1,465	102	4.9
Lone Oak	682	18	1,636	42	5.4
Russellville	1,040	18	2,120	60	4.9
Greenville	660	6	840	60	5.5
Berea	880	20	660	800	4.5
Fariston	820	14	1,000	580	4.5
Campbellsville	1,110	22	1.735	55	5.7

Yields are given from only such plats as may throw some light upon the response of crops to the various phosphates. The yields on the nearest check plats are given Bulletin 272 of the Kentucky Experiment Station gives the complete layout on each field.

The graphs are made up of the combined weights of the crops of the rotation. The average yields for the entire period of each field are used. Wheat grain and ear corn (70 pounds per bushel) are used.

The following symbols are used in tables and on graphs:

O = No limestone or fertilizers
L = Limestone
S = Superphosphate
R = Rock phosphate
K = Potash salts

RATES AND METHODS OF APPLICATION OF FERTILIZERS AND LIMESTONE

On the Mayfield, Lone Oak, Russellville, and Greenville soil experiment fields superphosphate (16%) was used at the rate of 800 pounds per rotation (4 years), beginning in 1913, the entire application being made broadcast on the corn ground, generally on the broken ground, and disked in. Fractional applications were made the first year on the other series proportional to the time when corn would appear on the series. Beginning with 1921, the application was reduced to 400 pounds per rotation. In 1925 the application asw shifted from corn to wheat.

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[1] Contribution from Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Summarized from a paper presented at the symposium on "Phosphorus" at the annual meeting of the Society held in Chicago, Ill., November 14, 1929.

[2] Head of Department.

[3] Analyses by Chemistry Department; pH values by P. E. Karraker of the Agronomy Department.

Rock phosphate of approximately 30% grade, guaranteed 90 to 95% through a 100-mesh sieve, was used in double the quantity of superphosphate and at the same time as superphosphate. Generally, the rock phosphate was applied before breaking the ground, until the applications were changed to the wheat ground.

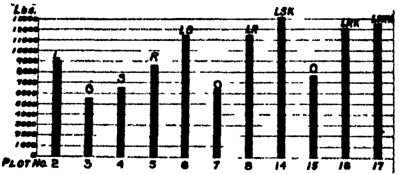

FIG. 1.—Comparison of combined weights of crops on Mayfield experiment field.

Muriate of potash or its equivalent was used at the rate of 200 pounds per acre per rotation, except that for the first three years 400 pounds were used, applied at the same time and in same way as superphosphate.

Ground limestone was used at the rate of 2 tons per acre for two rounds of the rotation at the same time as fertilizers, with fractional applications in the beginning as in the case of phosphates. One exception occurred in the case of a 4-ton per acre application made one year at Greenville. Liming was finished in 1920.

The rotation on these four fields is corn, soybeans, wheat, and clover, with a rye crop following corn. Timothy has frequently been used in mixture with the clover, and in later years alfalfa and lespedeza. This has also been the case on the Berea, Fariston, and Campbellsville fields.

THE MAYFIELD EXPERIMENT FIELD

Manure was used on the corn series from 1916 to 1919 at a uniform rate of 6 tons per acre on all plats, including checks. From 1921 to date, manure was used on each plat of the corn series equal to the weight of crops removed from the corresponding plats the pervious year, except that for two years a uniform application was used equal to the average weight of crops removed from the check plats the previous year (wheat grain not included). The soil of this field is classified as "yellow silt loam" in an independent soil survey. It is probably the Memphis silt loam of the U. S. Bureau of Soils. The crop yields are given in Table 1 and shown graphically in Fig. 1.

TABLE 1.—*Crop yields on the Mayfield experiment field.*

Plat No	2	3	4	5	6	7	8	14	15	16	17
Treatment	L	O	S	R	LS	O	LR	LSK	O	LRK	LSKN
Corn, bushels, ave. 15 crops.	37.6	28.2	30.8	37.2	44.4	32.2	44.4	48.2	35.9	45.1	44.3
Soybean hay, pounds, ave. 13 crops ..	3,070	2,391	2,657	2,922	3,543	2,575	3,640	4,137	3,081	3,984	4,026
Wheat, bushels, ave. 14 crops.	10.6	5.9	9.3	11.6	17.2	7.6	17.5	21.0	8.1	14.7	20.0
Clover, pounds, ave. 12 crops.	2,664	788	1,130	2,361	3,745	1,028	3,638	4,407	1,561	4,039	4,134

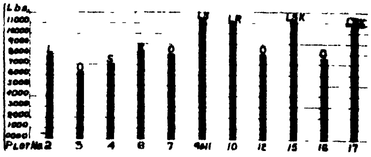

FIG. 2.—Comparison of combined weights of crops on Lone Oak experiment field.

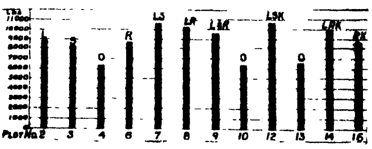

FIG. 3.—Comparison of combined weights of crops on Russellville experiment field.

THE LONE OAK EXPERIMENT FIELD

Manure was used on this field for one round of the rotation, 1916-19, at a uniform rate of 6 tons per acre on the corn ground. After this, the cornstalks and wheat straw were returned. Plat work on this field was discontinued at the end of 1923, except for the corn crop which was extended for two years. In a soil survey by the U. S. Bureau of Soils, in 1906, this soil is classed as Memphis silt loam. The crop yields are given in Table 2 and are shown graphically in Fig. 2.

TABLE 2.—*Crop yields on the Lone Oak experiment field.*

Plat No .	2	3	4	6	7	9+11	10	12	15	16	17
Treatment ..	L	O	S	R	O	LS	LR	O	LSK	O	LRK
Corn, bushels, ave. 13 crops .	36.2	31.0	33.3	35.4	36.8	41.7	43.8	35.1	40.6	33.2	43.1
Soybean hay, pounds, ave. 9 crops	2,591	2,264	2,504	2,735	2,809	3,488	3,507	2,790	3,442	2,609	3,293
Wheat, bushels, ave. 10 crops...	10.8	10.1	11.6	12.5	10.3	18.8	17.9	12.2	19.5	12.4	16.2
Clover, pounds, ave. 7 crops....	2,091	1,207	1,563	2,303	1,924	3,748	3,389	1,939	3,727	1,909	3,364

THE RUSSELLVILLE EXPERIMENT FIELD

Manure was used in the same way as at Mayfield until the discontinuance of the field at the end of 1924. The soil is classified as

Decatur silt loam. It is residual from the St. Louis limestone. The crop yields are shown in Table 3 and are depicted graphically in Fig. 3.

TABLE 3.—*Crop yields on the Russellville experiment field.*

Plat No.	2	3	4	6	7	8	9	10	12	13	14	16
Treatment	L	S	O	R	LS	LRL	1/2R	O	LSK	O	LRK	RK
Corn, bushels, ave. 11 crops	38.7	37.1	30.0	35.8	46.3	45.2	44.1	32.7	46.1	33.9	45.1	37.1
Soybean hay, pounds, ave. 11 crops	2,660	2,431	2,003	2,518	2,770	2,753	2,598	2,020	2,894	2,121	2,755	2,534
Wheat, bushels, ave. 9 crops	10.2	13.2	10.0	15.5	18.3	16.0	14.8	11.1	19.1	12.1	15.0	14.7
Clover, pounds, ave. 9 crops	2,816	2,381	1,626	2,657	3,523	3,420	3,059	1,369	3,407	1,313	3,137	2,591

THE GREENVILLE EXPERIMENT FIELD

Manure was used on this field, for corn, at the rate of 6 tons per acre on all plats from 1916–19. Cornstalks were left on ground and wheat straw was returned to corn ground from 1920 to 1924. Manure was used on corn ground in 1925–26 equal to weight of crops removed from corresponding plats the previous year. In 1927–28, manure was returned to all plats at a uniform rate equal to crops removed from check plats. The soil of this field is classed as Tilsit silt loam, and is derived from interbedded shale and sand-

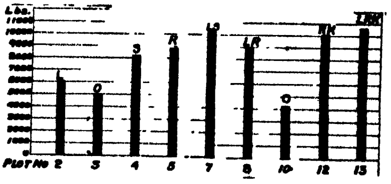

FIG. 4.—Comparison of combined weights of crops on Greenville experiment field.

TABLE 4.—*Crop yields on the Greenville experiment field.*

Plat No.	2	3	4	5	7	8	10	12	13
Treatment	L	O	S	R	LS	LR	O	RK	LRK
Corn, bushels, ave. 15 crops	29.3	26.9	34.8	35.9	42.0	38.5	22.7	40.9	45.5
Soybean hay, pounds, ave 15 crops	2,402	2,003	2,854	2,977	3,500	3,129	1,848	3,260	3,433
Wheat, bushels, ave. 14 crops	6.2	4.7	9.7	11.4	15.1	12.2	4.4	13.5	13.4
Clover, pounds, ave. 14 crops	1,242	846	2,345	2,646	2,999	2,427	554	3,206	3,224

stone. It is a poorly drained piece of soil, having a tight subsoil. In 1916, tile drainage was installed in the roadways between the series—a distance of 120 feet between lines. Crop yields are given in Table 4 and are shown graphically in Fig. 4.

THE BEREA EXPERIMENT FIELD

The soil of this field is classed as DeKalb silt loam and is derived from Devonian shale. It has a tight subsoil. Work was begun in 1913. Tile drainage was installed in 1917. A four-year rotation is used, consisting of corn followed by rye cover crop, soybeans, rye clipped down, and clover. Fertilizers have been applied as at Mayfield, except that the entire applications have been on the corn. The rock phosphate has been applied before breaking the ground for about two-thirds of the time. After liming two rounds of the rotation, as at Mayfield, liming was left off until 1928, when three series were limed again in 1928 and 1929 at the rate of 1 ton per acre. Manure was used at the rate of 6 tons per acre for corn on all plats from 1917 to 1921; since then as at Mayfield. Crop yields are recorded in Table 5 and are shown graphically in Fig. 5.

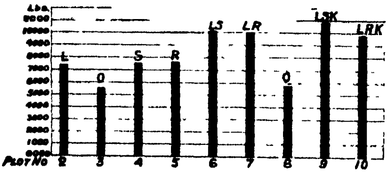

FIG. 5.—Comparison of combined weights of crops on Berea experiment field.

TABLE 5.—*Crop yields on the Berea experiment field.*

Plat No	2	3	4	5	6	7	8	9	10
Treatment	L	O	S	R	LS	LR	O	LSK	LRK
Corn, bushels, ave. 16 crops .	40.0	29.5	38.5	38.3	44.7	44.7	28.1	47.3	44.1
Soybean hay, pounds, ave. 16 crops	3,681	2,951	3,706	3,552	4,502	4,476	3,173	4,913	4,255
Clover, pounds, ave. 11 crops.	885	529	1,114	1,372	2,499	2,421	578	2,692	2,431

THE FARISTON EXPERIMENT FIELD

The soil of this field is a silt loam (not mapped) derived from shale and sandstone. The rotation was corn (rye cover crop), soybeans, wheat, and clover until 1923, when rye (clipped down) was substituted for wheat. Until 1925, a cowpea or soybean crop was planted after clover harvest and turned under, followed by a cover crop followed by corn. Superphosphate has been used at the rate of 800 pounds per acre per rotation, and rock phosphate at 1,600 pounds per acre. One-half of the superphosphate has been used on the corn and one-half on the winter grain or soybeans. For the first round of the rotation, rock phosphate was used the same way. After that, it was all applied to the corn ground. Some of the earlier applications of rock phosphate were made on unbroken ground and plowed under. Beginning with 1928, the applications were reduced one-half. Six tons of limestone per acre, in three applications, were used from 1916 to 1923. No manure has been used on the crops shown in Table 6 and graphically shown in Fig. 6.

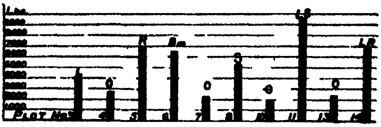

FIG. 6.—Comparison of combined weights of crops on Fariston experiment field without manure.

TABLE 6.—*Crop yields on the Fariston experiment field without manure.*

Plat No	3	4	5	6	7	8	10	11	13	14
Treatment	L	O	R	BM*	O	S	O	LS	O	LR
Corn, bushels, ave. 13 crops	18.2	9.5	33.9	30.4	8.7	26.0	6.7	42.0	9.7	28.8
Soybean hay, pounds, ave. 13 crops	2,007	1,532	2,894	2,763	1,334	2,110	1,161	3,915	1,321	2,872
Wheat, bushels, ave. 4 crops	5.6	3.6	7.9	10.1	2.5	7.3	3.2	12.1	3.4	6.4
Clover, pounds, ave. 10 crops	532	276	1,136	928	164	873	92	2,051	184	1,516

*BM = Steamed bone meal equivalent to superphosphate.

For the years 1925-1928 the plats were divided, with manure used on one-half at a uniform rate of 6 tons per acre, for corn, on all plats, including checks. The corn yields obtained are given in Table 7.

TABLE 7.—*Corn yields on the Fariston experiment field with manure.*

Plat No.	3	4	5	6	7	8	10	11	13	14
Treatment	L	O	R	BM	O	S	C	LS	O	LR
Average last 4 crops										
No manure	19.1	8.1	32,5	25.5	4.6	25.2	5.4	47.0	6.5	31.4
6 tons manure	32.2	20.5	40.7	29.9	13.8	23.9	12.1	50.9	13.4	40.6

THE CAMPBELLSVILLE EXPERIMENT FIELD

Work was begun on this field in 1919. The soil is a silt loam (not mapped) derived from the upper Waverly limestone and shale. The rotation is corn, wheat, and clover. Limestone has been used twice at the rate of 2 tons per acre, the first application being made in 1919 when work was begun, and the second application from 1922 to 1924 when the respective series came to corn. The phosphates have been used at the different rates shown in Tables 8 and 9. These amounts were applied on the corn ground for the rotation. The applications were repeated for each rotation. The rock phosphate was applied before breaking through 1925; after that, on the broken ground.

Manure was used uniformly on all plats, for corn, at the rate of 6 tons per acre in 1926 to 1928. Cowpeas were turned under for the corn crop of 1920, and on account of clover failure, they were grown and turned under for the corn crops of 1924 and 1925. A light stand of crimson clover was turned under for the corn crop of 1921. The yields are shown graphically in Fig. 7.

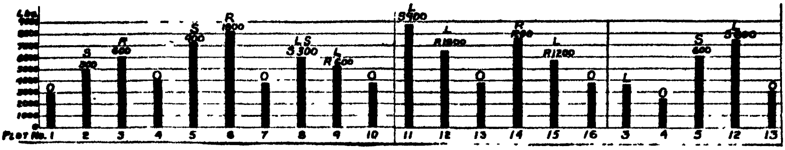

FIG. 7.—Comparison of combined weights of crops on Campbellsville experiment field.

TABLE 8.—*Crop yields on the Campbellsville experiment field.*

Plat No.	1	2	3	4	5	6	7	8	9	10	11
Treatment	O	S 300	R 600	O	S 900	R 1,800	O	LS 300	LR 600	O	LS 900
Corn, bushels, ave. 9 crops	22.0	38.1	42.6	30.2	47.7	49.9	30.2	44.9	38.4	29.8	54.3
Wheat, bushels, ave. 6 crops	4.5	7.6	10.1	6.0	12.2	12.4	5.4	10.7	8.4	5.8	15.7
Clover, pounds, ave. 8 crops	1,036	1,817	2,490	1,473	3,173	3,938	1,335	2,198	2,047	1,275	4,001

Plat No.	12	13	14	15	16	3*	4*	5*	12*	13*
Treatment	LR 1,800	O	R 1,200	LR 1,200	O	L	O	S 600	LS 600	O
Corn, bushels, ave. 9 crops	44.8	29.3	46.4	40.8	28.2	28.5	21.5	46.4	51.4	25.0
Wheat, bushels, ave. 6 crops.	10.3	6.3	11.5	9.1	7.7	5.7	2.8	9.4	10.9	3.9
Clover, pounds, ave. 8 crops.	2,778	1,404	3,657	2,345	1,353	1,294†	746†	2,237†	3,141†	1,076†

*These plats on different series from preceding ones of same number.
†Average of 7 crops.

On this field is a comparison of superphosphate and basic slag phosphate of equal grade and used in equal weights—600 pounds per acre per rotation—applied on corn ground. The yields obtained are given in Table 9.

TABLE 9.—***Crop yields on the Campbellsville experiment field following applications of superphosphate and basic slag.***

Plat No.	9	10	11	16	17	18	19
Treatment	SKN	O	BsKN*	O	LSKN	LBsKN	O
Corn, bushels, ave. 9 crops	51.0	28.0	49.0	28.7	53.5	50.6	25.2
Wheat, bushels, ave. 6 crops	14.5	4.0	13.8	4.6	16.5	16.4	4.6
Clover, pounds, ave. 7 crops	2,671	1,370	2,769	1,027	3,316	3,027	853

*Bs = Basic slag.

DISCUSSION

When all crops are considered, the yields from rock phosphate used without lime have in all cases been equal to or higher than the yields from superphosphate used without lime, the two phosphates being used in the ratio of 2:1. This relation is so consistent that it can hardly be said that it is mere chance due to soil variation. In some cases the margin for rock phosphate increased with time.

On some soils rock phosphate seems to be practically as effective with lime as superphosphate with lime, both combinations being superior to either of the phosphates used alone or to lime used alone. (See Mayfield, Lone Oak, Russellville, and Berea results.)

In other cases the combination of lime and rock phosphate appears slightly superior to rock phosphate alone, as at Greenville, but not so effective as lime and superphosphate. The period of heaviest liming seemed to depress clover yields from lime and rock phosphate below rock phosphate without lime, on this field.

In some cases rock phosphate is decidedly superior to superphosphate when used without lime, as at Fariston and Campbellsville. At Fariston, rock phosphate with lime is inferior to rock phosphate alone, except for clover and beans toward the end of the period. In the case of clover, the last three crops with lime and rock phosphate are practically equal to lime and superphosphate. Lime and superphosphate have been far more effective than superphosphate alone. On this field the steamed bone meal equivalent of superphosphate has been intermediate between rock phosphate and superphosphate on unlimed soil, except in the case of wheat, where it is superior to the other forms. At Campbellsville, on unlimed soil, rock phosphate has been superior to superphosphate when used in the ratio of 2:1; but when used on limed ground, it is far inferior. On limed ground rock phosphate is inferior to rock phosphate alone. In some cases rock phosphate alone is the equivalent of lime and superphosphate. It is interesting to note that basic slag is not depressed by lime to any significant extent, if at all.

It is recognized that the use of manure may possibly have obscured the relative effects of the two forms. For example, superphosphate may have supplied all the phosphorus necessary for any crop that may have been grown, while in the case of rock phosphate the manure may have supplied the margin of deficiency. However, an examination of the data does not substantiate the assumption.

There seems to be no relation between the behavior of the phosphates and the total or soluble phosphorus content of the soil, the lime requirement of the soil, as measured by either the Hopkins or

Veitch method, the soluble calcium of the soil, or the pH value of the soil.

Where lime used alone produces a significant effect as compared with superphosphate used alone, rock phosphate seems to function well in the presence of lime, as at Mayfield, Lone Oak, Russellville, and Berea. Where lime alone produces small effect as compared with superphosphate alone, lime seems to depress the effect of rock phosphate, as at Fariston and Campbellsville. Greenville seems to be intermediate in this respect.

If the exact nature of the soil conditions that cause these different behaviors could be discovered and if a means could be discovered for setting up the conditions under which rock phosphate functions well, it might become a very economical source of phosphorus on those soils where phosphorus is such an important factor, as in the case of the soils which this paper discusses

It is suggested that a small amount of finely ground lime used far enough ahead of the use of rock phosphate to permit the disappearance of calcium carbonate from the soil might be a solution of the difficulty where lime interferes with the availability of rock phosphate.

Even if adverse soil conditions could not be remedied, it would be highly desirable to have some quick test by which it could be determined whether the use of this form of phosphate would be desirable.

Fortunately, the older fields were laid out in tenth-acre plats with 8-foot alleys which permit the division of plats. It is planned to leave off the application of rock phosphate on one-half of some of the plats for a period of t me in order to get the residual effect of the accumulated phosphate. On others where no lime has been used, it is planned to use a small amount of very fine lime. On some plats where only lime has been used and where a long period of time has elapsed since liming, it is planned to add rock phosphate to part of the plat.

At Campbellsville, where 1,800 pounds per acre of rock phosphate have been used, practically 1,000 pounds of phosphorus have been added in 12 years. The original content was about 1,000 pounds per acre 6 inches. Applications will be discontinued on these plats. The 1,200-pound and 600-pound rates will be continued until the total of the 1,800-pound applications has been reached, thus giving an opportunity to study the residual effect of large accumulations.

EFFECTS OF SUPERPHOSPHATES UPON THE GERMINATION OF CORN[1]

C. O. Rost[2]

When, during planting operations, too much soluble commercial fertilizer is allowed to come into contact with the seed, germination is inhibited or completely prevented. The extent of damage depends upon the kind and amount of fertilizer used and upon the manner in which it is applied. A number of studies of the effect upon germination of different amounts of fertilizers and varying methods of placement in relation to the seed have been reported and are listed in a recent bibliography by Truog.[3] In these the effect of 16% superphosphate has received considerable attention, but of the more concentrated forms of superphosphate the only report is one by Millar and Mitchell[4] who, in greenhouse trials with white beans, compared a concentrated superphosphate with both 16% superphosphate and a complete fertilizer. They found the concentrated superphosphate to be much more toxic than the 16% material when placed either in direct contact with the seed or above it.

In Minnesota the use of concentrated superphosphates has become general so that their effect upon the germination of corn is of great interest. In the present paper are reported data on the subject secured in the seasons of 1928 and 1929

EXPERIMENTAL

In the present study two methods of placement of the fertilizers were employed, in the one they were spread over an area 6 by 10 inches and mixed with the soil to a depth of 3 inches, and in the other they were applied with a fertilizer attachment to the corn planter. In 1928, 16% and 46% superphosphate were compared on three fields, one on Hempstead silt loam, one on Merrimac loamy sand, and the other on high-lime peat. They were also compared in the plant house using pots filled with Hempstead silt loam. In 1929, the experiments were confined to the second method used in the field on Hempstead silt loam.

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[1] Contribution from the Division of Soils, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Paper No. 905 of the Journal Series. Received for publication December 9, 1929.

[2] Associate Soils Chemist.

[3] Truog, E. Reports and proceedings of the joint committee on fertilizer application, 1925–28. Nat. Fert. Assoc. 1928.

[4] Millar, C. E., and Mitchell, J. F. Effect of rate and method of application of fertilizer on the germination of white beans. Jour. Amer. Soc. Agron., 19: 270–279. 1927.

APPLICATIONS ON 6 BY 10 INCH AREA PER HILL

When applying the fertilizer on the 6 by 10 inch area, a wide board having an opening of these dimensions was laid on the ground, the fertilizer scattered uniformly over this small area, and worked into the soil to a depth of 3 inches with a trowel. Then, on the same day, with a hand planter, the corn was planted in the center of the rectangle. This method of application was used only in the 1928 experiments.

Concentrated superphosphate carrying 46% P_2O_5 was applied in this manner at rates of 125, 250, 500, 1,000, 1,500, and 2,000 pounds per acre and the 16% superphosphate in amounts carrying equivalent quantities of P_2O_5, *viz.*, 360, 720, 1,440, 2,880, 4,320, and 5,760 pounds of the superphosphate per acre. With each rate of both fertilizers there were duplicate plats of 10 hills each, and there were 6 unfertilized or control plats each with 10 hills. The number of plants per hill on the control plats is shown in detail in Table 1. The average for Hemstead silt loam was 3.4, for Merrimac loamy sand 3.7, and for the high-lime peat 3.9. The averages of the six plats are used in Table 2 which reports the number of plants per hill on the fertilized plats.

TABLE 1.—*Number of plants per hill on control plats.*

Plat No.	Hills with					Average number per hill
	No plants	1 plant	2 plants	3 plants	4 plants	
			Hempstead Silt Loam			
1	1	1	6	4	8	2.8
13	0	0	0	2	18	3.9
25	0	2	2	5	11	3.2
37	0	0	3	5	12	3.4
49	0	0	1	5	14	3.6
51	0	1	2	1	16	3.6
Ave.	0	1	2	4	13	3.4
			Merrimac Loamy Sand			
1	1	0	1	1	17	3.6
13	0	0	1	1	18	3.8
25	0	2	1	7	10	3.2
37	0	0	1	2	17	3.8
49	0	1	0	2	17	3.7
51	0	0	0	2	18	3.9
Ave	0	1	1	2	16	3.7
			High-lime Peat			
1	0	0	0	0	20	4.0
13	0	0	0	1	19	4.0
25	0	0	0	1	19	4.0
37	0	0	2	2	16	3.7
49	0	0	1	1	18	3.8
51	0	0	2	2	16	3.7
Ave	0	0	1	1	18	3.9

TABLE 2. *Number of plants per hill with different amounts of superphosphate, the fertilizer being applied on an area 6 by 10 inches and the seed planted in the center.*

			Hemstead silt loam Hills with					Merrimac loamy sand Hills with					Peat Hills with				
Plat No.	Type of super-phosphate	Pounds per acre	No plants	1 plant	2 plants	3 plants	4 plants	No plants	1 plant	2 plants	3 plants	4 plants	No plants	1 plant	2 plants	3 plants	4 plants
—*	None	—	0	1	2	4	13	0	1	1	2	16	0	0	1	1	18
3,28	46%	125	0	1	0	3	16	0	0	1	2	17	0	0	1	1	18
4,29	46%	250	0	0	4	1	15	0	1	3	5	12	0	0	0	2	18
5,30	46%	500	0	0	1	6	13	1	0	2	5	12	1	0	0	0	19
6,31	46%	1,000	2	4	3	6	5	6	8	3	1	2	1	0	3	4	12
7,32	46%	1,500	6	8	4	2	0	11	6	1	1	1	9	1	6	3	1
8,33	46%	2,000	17	3	0	0	0	14	4	1	0	1	15	3	2	0	0
16.40	16%	360	0	0	0	5	15	0	1	0	2	17	0	0	0	0	20
17,41	16%	720	0	2	3	3	12	0	2	1	2	15	0	0	0	1	19
18,42	16%	1,440	0	1	2	2	15	0	2	3	1	14	0	0	0	2	18
19,43	16%	2,880	0	0	1	6	13	1	3	0	4	12	0	0	0	2	18
20,44	16%	4,320	1	7	3	5	4	1	8	6	4	1	1	2	0	5	10
21,45	16%	5,760	7	5	5	1	2	8	4	3	3	2	4	6	2	6	2

*Average of 6 plats reported in Table 1.

The effect of 46% superphosphate was much the same on all three fields. The results for this season indicate that any amount up to 500 pounds per acre may be applied in this manner with no effect on the germination of corn. When applied at 1,000 pounds or more the germination was affected more and more as the amount was increased, until at the 2,000-pound rate the seed in three-fourths of the hills failed to germinate and in the other fourth the number of plants was reduced to one or at most two per hill. Applied in this manner 500 pounds would give the same concentration of phosphoric acid in the soil around the seed as a broadcast application of 14,635 pounds per acre.

The 16% superphosphate had little or no harmful effect upon the stand when the rate was not above 2,880 pounds per acre or an amount carrying the P_2O_5 equivalent of 1,000 pounds of 46% superphosphate. An application of 4,320 pounds per acre or more reduced the stand, but neither the 4,320- nor the 5,760-pound rate was as toxic as the equivalent amount of P_2O_5 in the form of 46% superphosphate. The 2,880-pound rate in the hill would be equivalent to 84,680 pounds per acre broadcast. The effect of heavy applications of both fertilizers was less harmful on the peat than on the two mineral soils and was less harmful on the silt loam than on the loamy sand. It appears that neither fertilizer when applied at the rates ordinarily used in farm practice has any ill effect upon the germination of corn. When used in excessive amounts, the 16% superphosphate appears less toxic to corn than the equivalent rate of the 46% product.

RESULTS UNDER PLANT HOUSE CONDITIONS

For the experiment in the plant house, pots 8 inches in diameter and 12 inches deep were filled with Hempstead silt loam. The two superphosphates were applied at the same rate and in the same manner as on the 6 by 10 inch area in the field. The proper amount of fertilizer for each pot was weighed out, worked into the soil to a depth of 3 inches, and four kernels of corn planted in each pot. The count of plants that appeared above the surface of the soil indicated the germination.

In the first trial the corn was planted on Jan. 4, 1929, the same day that the fertilizer was applied, while the second trial was started on Feb. 1, immediately after removing the plants from the pots at the end of the first trial. The only difference between the two trials was that the fertilizer had been incorporated with the soil approximately one month before the second trial was started.

When the first trial was made severe weather conditions made it difficult to maintain the optimum temperature for germination with the result that on the average 10 days were required for plants to appear above the surface on the controls (Table 3).

TABLE 3.—*Effect of superphosphates, under plant house conditions, upon the germination of corn, with seed planted on day fertilizer was applied.*

Jar No.	Type of super-phosphate	Pounds per acre	Days to appearance of First plant	Second plant	Third plant	Fourth plant	Average	Total number plants
1	None	—	8	9	10	10		
2	None	—	8	9	11	14	10	8
15	None	—	9	9	10	11		
16	None	—	7	10	11	11	10	8
3	46%	125	8	9	10	13		
4	46%		10	10	10	12	10	8
5	46%	250	11	12	12	17		
6	46%		13	13	14	22	14	8
7	46%	500	17	18	26	—		
8	46%		16	17	—	—	19	5
9	46%	1,000	16	18	25	—		
10	46%		19	21	21	25	21	7
11	46%	1,500	18	23	23	24		
12	46%		19	20	20	21	21	8
13	46%	2,000	29	—	—	—		
14	46%		26	—	—	—	28	2
17	16%	360	10	11	11	11		
18	16%		10	10	—	—	10	6
19	16%	720	13	13	14	—		
20	16%		12	14	18	18	14	7
21	16%	1,440	13	14	17	—		
22	16%		14	17	18	28	17	7
23	16%	2,880	14	15	18	23		
24	16%		13	14	17	21	17	8
25	16%	4,320	16	23	24	24		
26	16%		17	17	20	—	20	7
27	16%	5,760	25	28	29	—		
28	16%		25	—	—	—	27	4

The time of germination with 125 pounds of 46% superphosphate was the same as on the controls, but with all rates heavier than this the time required for plants to appear was longer, an average of 14 days being required with 250 pounds and 28 days with the 2,000-pound rate. The average time of germination with 360 pounds of 16% superphosphate, equivalent in P_2O_5 to 125 pounds of 46% superphosphate, was 10 days as on the controls; but with larger amounts, as with the 46% superphosphate, there was required a longer period of time for plants to appear. In general, the average number of days elapsing before plants appeared was less than with 46% superphosphate.

There was little difference in the stand secured with the two fertilizers. Not until the rate reached 2,000 pounds of 46% superphosphate or 5,760 pounds of 16% superphosphate was the number of plants seriously reduced. In this respect there appears to be a discrepancy between the results secured in the field and those obtained from the pot tests. Since the plants in the pots were removed very shortly after they appeared, it is not known how many would have survived in the case of the heavier applications. The plants in these were very weak and the indications were that many of them would have succumbed. This was indicated by marginal necrosis of the leaves and by the appearance of a condition similar to wilting. On the pots receiving 46% superphosphate in amounts of 1,000 pounds or more, these conditions were generally more pronounced than on those receiving equivalent amounts of 16% superphosphate.

The soil in the pots was kept moist by frequent watering so that at no time did it become very dry. In the field there was no such uniformity of moisture conditions and it is not unlikely that this would account for some of the difference between the field and plant house results in the case of the heavy applications.

In Table 4 are given the results secured in the second trial where the seed was planted immediately following the removal of the plants of the first trial but after the fertilizer had been mixed with the soil for a month. Temperature conditions were more favorable for germination and plants appeared on the controls in 5 days. Application of 125 pounds of 46% superphosphate and 360 pounds of 16% superphosphate had no effect upon the time of appearance of plants, but larger amounts delayed it A maximum of 14 days with an average of 9 days was found in the case of the heaviest applications.

With no rate was the number of plants appearing less than 7 out of a possible 8 The plants were permitted to grow in the pots for a month in order to observe their behavior. The number and height at the end of this time is reported in Table 4. In most cases, except with 2,000 pounds of 46% superphosphate and 5,760 pounds of 16% superphosphate, all the plants were alive at the end of the month. With 1,000 pounds or more of 46% superphosphate the general condition of the plants was unhealthy.

The results from the second trial indicate that the heavier applications of both fertilizers were less harmful when the fertilizers had been in intimate contact with the soil a month before the seed was planted.

APPLICATION BY FERTILIZER ATTACHMENT TO PLANTER

The corn planter with fertilizer attachment used, which was one of latest design, did not permit the seed and fertilizer to come into direct contact. In the first season, 1928, only one rate of application was tried, the machine being set to put on the largest amount it

TABLE 4.—*Effect of superphosphates, under plant house conditions, upon the germination of corn, the fertilizer being applied a month in advance of planting.*

			Days to appearance of					Number of plants		Height after
Jar No.	Type of superphosphate	Pounds per acre	First plant	Second plant	Third plant	Fourth plant	Average	At start	After 1 month	1 month, inches
1	None	—	5	5	5	6	–	4	4	33
2	None	—	5	5	5	5	5	4	4	28
15	None	—	5	5	6	7	–	4	4	30
16	None	—	4	5	5	6	5	4	4	26
3	46%	125	5	5	6	7	–	4	4	24
4	46%	125	5	5	5	6	5	4	4	27
5	46%	250	5	5	5	6	–	4	4	27
6	46%	250	5	6	7	12	6	4	4	29
7	46%	500	7	7	10	12	–	4	4	25
8	46%	500	6	8	8	9	8	4	4	21
9	46%	1,000	6	6	7	9	–	4	4	22
10	46%	1,000	6	6	6	–	7	3	3	24
11	46%	1,500	6	6	7	7	–	4	3	16
12	46%	1,500	6	7	15	–	8	3	3	16
13	46%	2,000	9	9	12	–	–	3	1	10
14	46%	2,000	6	8	9	14	9	3	2	12
17	16%	360	6	6	6	6	–	4	4	28
18	16%	360	5	6	6	–	6	3	3	28
19	16%	720	5	6	6	10	–	4	3	30
20	16%	720	6	7	7	10	7	4	4	26
21	16%	1,440	6	6	7	–	–	3	3	31
22	16%	1,440	7	7	8	8	7	4	4	27
23	16%	2,880	6	6	6	6	–	4	4	28
24	16%	2,880	6	6	6	7	6	4	4	25
25	16%	4,320	7	7	9	9	–	4	3	26
26	16%	4,320	6	6	7	13	8	4	4	28
27	16%	5,760	6	8	9	14	–	4	3	21
28	16%	5,760	7	9	9	13	9	4	3	25

could deliver. The rate for 46% superphosphate was 415 pounds per acre but only 320 pounds per acre of the 16%. The former was drier and less sticky and ran from the hopper more freely. Both were used on the three fields mentioned above. Full stands were secured with both 46% and 16% superphosphate. There was a full agreement on all fields between this method of application and that of mixing the fertilizer in a 6 by 10 inch area. The maximum amount which the attachment to the planter would apply was not sufficient to affect germination.

In the season of 1929 the effect upon the germination of corn of a number of different fertilizers was studied and 46% superphosphate was included, although the results in the previous season had indicated that the maximum amount which could be applied with the attachment to the planter was without effect.

Two plats, one of 68 and the other of 62 hills, were planted on May 23, with the attachment set to deliver the largest amount possible and two similar plats with it set to deliver approximately half as much. The heavier application was at the rate of 350 pounds and the lighter at 200 pounds per acre. One month after planting the missing hills were counted on the control and fertilized plats On plat 1 a count of the plants per hill was also made. The data are reported in Table 5. Of the two plats on which 350 pounds per acre of 46% superphosphate were applied, plat 1 with 68 hills had 20 hills with no plants and plat 2 with 62 hills had 24 with no plants. A count of the number of plants per hill on plat 1 showed 13 with one stalk and 15 with two. There were no missing hills on the two control plats and 133 of the 136 hills had three or four plants per hill. With the 200-pound application there was only one missing hill on the two plats and a count on plat 1 showed all hills to have either three or four plants except four which had two plants each. The results from this trial would indicate that a hill application of 46% superphosphate as heavy as 350 pounds per acre may have a harmful effect upon germination and may reduce the stand seriously. The 200-pound application appeared to have no serious effect.

TABLE 5.—*Effect on stand of corn in 1929 of 46% superphosphate when applied with attachment to planter.**

		Plat 1, hills with						Plat 2, hills with		
Row No.	Pounds per acre	No plants	1 plant	2 plants	3 plants	4 plants	Number of hills	No plants	1 or more plants	Total number hills
11...	350	20	13	15	6	14	68	24	38	62
12...	200	1	0	4	22	41	68	0	62	62
9...	None	0	0	3	7	58	68	0	62	62
10...	None	0	0	0	8	60	68	0	62	62

*Corn planted on May 23.

Early in July plat 2 was plowed up and on July 16 was planted to corn again, using both 46% and 16% superphosphate. In this experiment a new planter of the same make was used and when set to deliver the largest amount possible put on only 275 pounds per acre of 46% superphosphate and 265 pounds of the 16% material. Application of 175 pounds of 46% superphosphate and 125 pounds of 16% superphosphate were also used. The results are given in Table 6.

TABLE 6.—*Effect of superphosphates on germination of corn in 1929 when applied with attachment to planter.**

Row No.	Type of super-phosphate	Pounds per acre	No plants	Hills with 1 plant	2 plants	3 plants	4 plants†	Total hills
9....	46%	275	10	18	29	9	0	66
10....	46%	175	6	16	36	8	0	66
11....	16%	265	1	7	28	28	0	66
12....	16%	125	3	9	39	12	3	66
15....	None	0	5	15	26	19	1	66
16....	None	0	7	7	44	8	0	66

*Corn planted on July 16. †Planter set to drop three kernels.

On account of the dry condition of the soil it was difficult to prepare an entirely satisfactory seedbed. The field was somewhat cloddy even after considerable extra work. This condition coupled with the dry condition of the seedbed may account for the missing hills on the controls and for most of those on the fertilized plats. With 275 pounds of 46% superphosphate there were 10 missing hills out of a possible 66, while 18 hills had only one plant. The number of missing hills on the two controls was 5 and 7, while 15 and 7, respectively, had one plant. Both rates of 16% superphosphate had fewer missing hills than the controls and the number of plants per hill was fully as high. In this trial there were no harmful effects from fertilizer upon germination except possibly with the heavier rate of 46% superphosphate.

Thus, the results secured in 1928 indicated that any amount of 46% superphosphate up to 500 pounds per acre might be used as a hill application without interfering with the germination of corn, while in 1929 an application of 350 pounds per acre seriously interfered with germination. This difference in effect may have been due to a difference in the moisture supply in the soil in the two seasons. Truog, *et al.*[5], have shown that the effect of fertilizer upon the germination of corn is not only related to the amount of fertilizer used but also to the moisture content of the soil, the lower the moisture content the greater the damage from increasing amounts of fertilizer. The amount of soil moisture was not determined in either season, but the precipitation for May was practically the same in both, 2.26 inches having fallen in 1928 and 2.20 inches in 1929, and the distribution was similar. The precipitation for the month was below normal in both seasons.

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[5] TRUOG, E., HARPER, H. J., MAGISTAD, O. C., PARKER, F. W., and SYKORA, JAMES. Fertilizer experiments: Methods of application and effect on germination, early growth, hardiness, root growth, lodging, maturity, quality, and yield. Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.

The results would indicate that it is possible, using a fertilizer attachment to the planter set to put on the largest amount it can deliver, to put on a sufficiently heavy application of 46% superphosphate to be harmful to the germination of corn in certain seasons. The rates used in ordinary farm practice in Minnesota seldom exceed 125 pounds per acre of 46% material and usually are less than this when applied with a fertilizer attachment to the planter. It would appear that this is safely below the amount which would be harmful to germination

SUMMARY

The effect of different amounts of 16% and 46% superphosphate upon the germination of corn was tried under field conditions on three soils, *viz.*, Hempstead silt loam, Merrimac loamy sand, and a high-lime peat, and in the greenhouse on the Hempstead silt loam. In the field the fertilizers were applied with an attachment to the planter and also by mixing with the soil to a depth of 3 inches on a rectangular area of 6 by 10 inches for each hill. The latter method was used in the greenhouse trials.

Applied on 6 by 10 inch areas neither superphosphate showed a harmful effect on the germination of the corn when used at rates at all similar to those ordinarily employed in farm practice, but when the rates reached 10 to 20 times these amounts the germination on the 6 by 10 inch area was affected. Very large amounts of 46% phosphate appear to be more toxic than equivalent amounts of 16% superphosphate.

Pot tests under greenhouse conditions showed that very heavy applications of either fertilizer retarded germination, the larger the amount used the longer the time required for plants to appear above the surface. Here, as in field trials, large amounts of the more concentrated superphosphate appeared more harmful than equivalent amounts of the 16% product. The pot tests indicated that heavy applications of both fertilizers retard germination less when they have been in intimate contact with the soil for some weeks in advance of planting.

When applied with a fertilizer attachment neither 415 pounds per acre of 46% superphosphate nor 320 pounds per acre of 16% superphosphate had any harmful effect on the germination of corn in the season of 1928, but in the following year a similar application of 350 pounds per acre of the 46% material seriously affected the germination.

ARCHAEOLOGICAL EVIDENCE CONCERNING THE ORIGIN OF SWEET MAIZE[1]

G. W. Hendry[2]

Correns (1)[3] has demonstrated by means of genetic studies that the "sweet" character in maize endosperm is due to an inability to complete the formation of normal maize starch, that the presence or absence of this starch-forming ability acts as an independent character pair in inheritance, and that no other feature is peculiar to the sweet group.

East (4), by similar means, has proved that sweet maize varieties not only do not belong to a unit group, but consist of both dent and flint varieties which have lost their original starch-forming power. This condition in East's opinion may have appeared through mutation in each of these groups, but more likely first took place among the flint types and was extended by hybridization. Such signal evidence as this, reinforced by that of a more general nature, such as the recessiveness of the sweet character, the presence of an apparent extra pair of chromosomes in certain sweet varieties, and the fact that the sweet type is the least able of the maize endosperm types to survive in the wild state, seems to prove conclusively that sweet endosperm is of mutative origin and that it represents a later departure among the endosperm varieties of the species.

As to the probable time or place of such mutation or mutations, however, there has been no significant evidence except that of a negative kind, for the absence of sweet varieties among the innumerable maize specimens which have until now been recovered from various archaeological sites of pre-Columbian age may be interpreted as indicating that the type was unknown to the various human cultures represented by such excavations, and has suggested a modern or post-Columbian origin. The recent discovery, then, of what is thought to be an ear of sweet maize in a prehistoric Peruvian tomb illuminates to some extent these latter questions.

THE HUAMACHUCO EAR

The ear referred to (Fig. 1) is specimen No. 4-3613 of the Field Museum, and was loàned the writer, together with other prehistoric maize specimens, through the courtesy of Professor A. L. Kroeber, of the Department of Anthropology of the University of California.

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[1] Contribution from the Division of Agronomy, California Agricultural Experiment Station, Berkeley, Calif. Received for publication December 3, 1929.

[2] Associate Agronomist and Assistant Professor of Agronomy.

[3] Reference by number is to "Literature Cited," p. 513.

It was excavated from a prehistoric site near the town of Huamachuco, in the interior highlands of northern Peru, and in the opinion of the collector, M. Uhle, dates either from the actual Inca period or

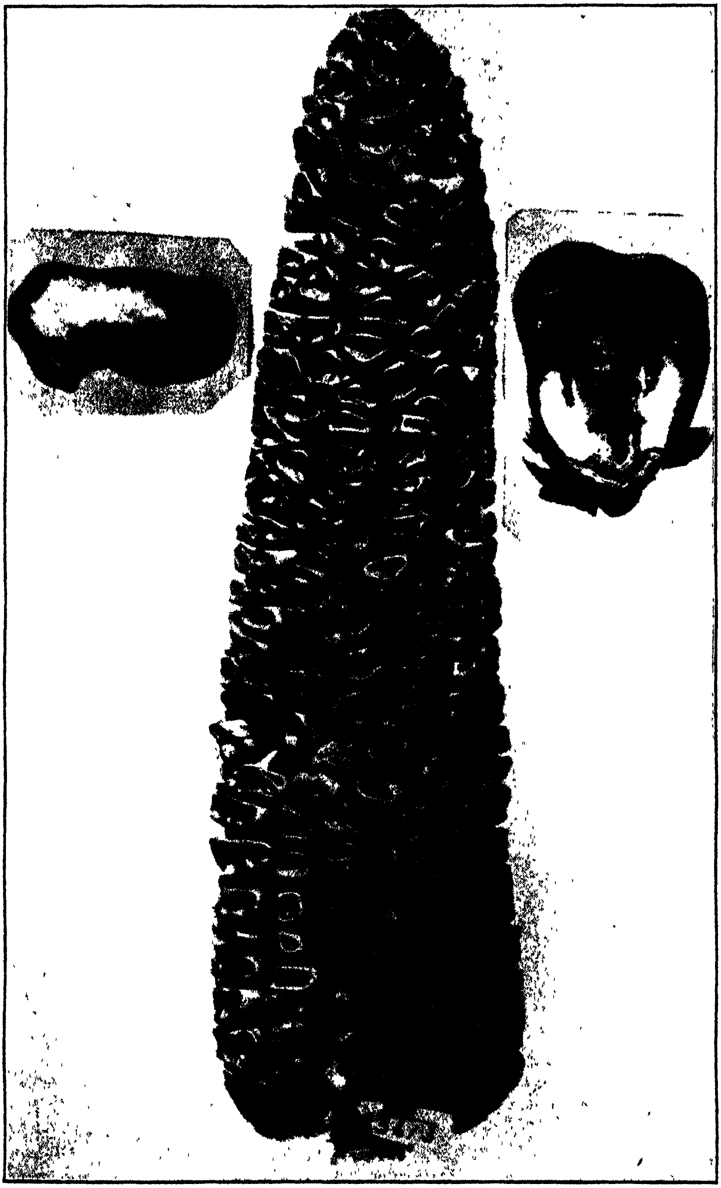

Fig. 1.—The Huamachuco ear with sections of representative kernels.

from the era immediately preceding, which fixes its origin between the years 1000 and 1534 A.D. Like numerous starchy and flint ears of equal and greater antiquity recovered from other Peruvian archaeological sites, the specimen has been extraordinarily well preserved by desiccation. Even the embryos appear surprisingly fresh and contain oil in the liquid form. Germination tests have failed to reveal indications of vitality, and since every precaution was taken by the collector to avoid error, and since no variety possessing identical characteristics is known today, the possibility that the specimen may be an accidental intrusion of modern material is remote.

DESCRIPTION

Ear.—7 3/8 inches long, 1 5/8 inches diameter, rounded and expanded at butt, tapering; 12-rowed, irregular.

Kernels.—Upright, widely separate, loose, 5/16 inch broad, 9/16 inch long, rounded corners, faceated, irregular, cuneate to truncate-cuneate, mucronate, tip and butt kernels depressed, coarsely crinkled and shriveled in upper portion, smooth in lower portion; maize yellow[4] at tip becoming translucent pale amber in upper crinkled portions; translucent portion hard, brittle, glassy, accentuated by lines of fracture and allowing embryo to be seen in silhouette; opaque portion confined exclusively to base of kernels near embryo, occupying in individual kernels from 10 to 75% of endosperm volume; nine kernels consist entirely of opaque endosperm; polysaccharide content high and comparable to that of modern sweet varieties in amount; starch grains indistinct, unequal in size, irregular in outline, imbedded in a large amount of polysaccharide material causing aggregation, average from various portions of kernel 5.16 μ in diameter, larger, more numerous, more unequal in size and irregular in opaque portion.

Ear stalk.—Medium.

Cob.—Red.

CLASSIFICATION

Because of the above-described characteristics the specimen is excluded from all of the recognized endosperm groups excepting sweet, and to this it bears a close affinity, not only in superficial appearance, but also chemically and cytologically. The studies of Magoon and Culpepper (7) and of Culpepper and Magoon (2, 3) have shown that sweet varieties differ from those of the other endosperm types chemically in that they have a markedly higher water-soluble polysaccharide content, and that this constituent, through its high water-absorbing capacity, both determines the shrivelled appearance of the mature seeds and imparts the creamy consistency which characterizes the roasting ears of the group. Since this character, then, is responsible both for the common appearance and table quality of the varieties of the group, it must be accounted the most significant chemical factor of use in the delineation of the group. The endosperm of the Huamachuco ear has been found to be comparable to the sweet varieties in this respect, and to stand in marked contrast to modern and ancient ears of the other types. Qualitative chemical tests established this relationship so clearly that exact quantitative determinations were not made.

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[4] Color terminology after Ridgway (8).

A second generic character of importance in the recognition of the mature seeds of sweet maize is to be found in the nature of the starch grains. These are typically small, indistinct, unequal in size, irregular in outline, and tend to aggregate because of their polysaccharide matrix, while those of the smooth-seeded endosperm types are larger, plumper, nearly round, distinctly marked, and unaggregated. Most sweet varieties have a small amount of opaque endosperm lying near the embryo at its base, but since the starch grains of this, while in part larger, are otherwise similar to those of the translucent portion, it is regarded as opaque-sweet rather than as opaque-starchy endosperm. The relative percentage of polysaccharides contained in the two types of sweet endosperm seems not to have been studied, but judging by the lesser degree of wrinkling the opaque regions probably contain less. The starch from both endosperms of the Huamachuco kernels is that of a sweet variety. A composite sample from various portions of the kernels was found to contain starch grains which averaged 5.16 μ in diameter as compared with 3.68 μ for those similarly taken from Golden Bantam and 12.9 μ for those from floury varieties of both modern and ancient origin. They were also unequal in size, irregular in outline, and aggregated. The most conspicuous apparent difference between the Huamachuco kernels and those of modern sweet varieties lies in the greater ratio of opaque to translucent endosperm possessed by the former. The starch of this, however, is sweet in character and therefore precisely analogous to that from the opaque portions of modern sweet varieties. The difference is thus one of degree and not of essential genetic constitution.

The possibility that the specimen may be an ancient example of the genetically distinct "pseudo-starchy" type described by Jones (6), and earlier described by East and Hays (5) as "semi-starchy," has been considered; but because it differs from this in such generic characters as the manner of distribution of opaque and translucent endosperm, amount of water-soluble polysaccharides, and in the character of the starch grains, it must be regarded as distinct from it. The specific differences are: First, the opaque endosperm of the Huamachuco ear, when associated with translucent endosperm in the same kernel, is invariably confined to the bases of the kernels, as is that of all true sweet varieties. The "pseudo-starchy" type, on the other hand, may have solid areas of opaque white endosperm at the center or at the tips of the seeds, and usually possesses a cavity surrounded by a small area of opaque white substance. No such cavity exists in the kernels of the Huamachuco ear. Second, the polysaccharide content of the Huamachuco kernels is high and comparable to that of true sweet varieties in amount, while that of the "pseudo-starchy" type is only about one-quarter as great and is characteristically that of the smooth-seeded varieties in amount.

There is a less clearly defined, although distinct, difference in the starch grains, but since the published description and illustrations of the "pseudo-starchy" type do not distinguish between the starch of the opaque and the translucent endosperm, but deal only with composite samples obtained by scraping across both portions, a detailed comparison is not possible. Upon the basis of such composite samples, however, it is apparent that the starch of the Huamachuco kernels is nearer that of modern sweet varieties in type than is that of "pseudo-starchy," although both possess sweet characteristics. In size and form the Huamachuco starch grains are distinctly sweet, while those of "pseudo-starchy" show considerable departure from type.

Sturtevant (9) has described three anomalous appearing varieties from the San Padro[5] Indian collection, sent him by Dr. Edward Palmer of the Smithsonian Institute in 1886. These appear to possess the gross endosperm characteristics of the Huamachuco ear. They differ from it, however, in minor varietal characters, such as number of rows of kernels and kernel shape. The character which distinguishes these three varieties from his six other species groups, and upon which he based a seventh group, *Zea amyleasaccharata,*—"the starchy sweet corns"—is in the internal arrangement of the kernel, the lower portion being starchy and the upper horny and translucent. But whether this lower portion is in fact starchy or whether it is opaque-sweet in character has yet to be determined, and consequently the validity of the group is questioned.

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[5] In his original description published in 1886, Sturtevant (9) states that this collection was made at the Indian village of San Pedro, Mexico, but later (10) refers to it as the San Padro Indian collection. I have been unable to find reference to a San Padro village or tribe in Mexico, but since Dr. Palmer also obtained specimens from the Cocopa and Tarahumara Indians, it seems probable that the reference is to San Pedro, Sonora, just south of Naco, Arizona, and midway between the above-named Indian regions. There is, however, a village of San Pedro in northwestern Chihuahua near the Sonora line, and another 40 or 50 miles south of Chihuahua City, also in Chihuahua.

Jones (6, page 371) is of the opinion that Sturtevant was probably dealing with examples of the "pseudo-starchy" type, but should the endosperm of these type specimens prove to be sweet throughout, both with respect to polysaccharides and starch, then the specimens would properly be classified as sweet varieties. The writer has recently examined three similar-appearing sweet varieties with variegated caryopses obtained from the Hopi Indians of Arizona. Employing Sturtevant's criteria, these, too, would be classified as *Zea amyleasaccharata,* but since they possess nothing but sweet endosperm—characterized by sweet starch and a high polysaccharide content—they are regarded as sweet varieties Like the Huamachuco ear, they differ from other sweet varieties only in possessing a higher ratio of opaque to translucent endosperm Evidently, a distinct group of sweet maize composed of many varieties exists among the Indian tribes of the arid Southwest. Sturtevant (10) added a fourth variety from Peru to his starchy-sweet group in 1890.

CONCLUSIONS

It seems reasonable to conclude as follows: First, that sweet maize has been derived through mutation from an older endosperm type or types, and that such mutation has occurred in at least one instance in the Peruvian highlands prior to 1534 A. D. Second, since only varieties of the floury and flint types are known to have existed there, or in neighboring regions, and since the specimen resembles the former in minor varietal characteristics, such as number of rows of kernels, kernel shape, etc., it seems probable that in this instance the sweet mutant first appeared in a variety of the floury type. Third, a distinct group of sweet varieties, possessing characteristics similar to the Huamachuco variety and possibly of similar genesis, is to be found under cultivation among the Indians of the arid Southwest, and probably in Peru.

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METHODS OF APPLYING FERTILIZERS TO WHEAT[1]

F. L. DULEY[2]

During recent years there has been an increasing interest in the methods of supplying fertilizer materials to various crops. The earlier idea seemed to be that if the soil was low in a given fertility element it could be added by almost any method and satisfactory crops would result. This idea is giving way to the practice of fertilizing each crop by the method that will produce in it the most economical increases. In other words, we are coming more and more to the idea of "fertilizing the crop" rather than "fertilizing the soil." A considerable amount of work has already been done on methods of fertilizing cotton, potatoes, corn, and other crops.

In the past the experiments in the use of fertilizers on wheat in Kansas have had the fertilizer applied broadcast on the surface and worked into the soil by disking and harrowing. The results have shown slight increases for fertilizer in many cases, but the increases have not been large enough to stimulate a widespread interest in the use of fertilizer materials. In the soil fertility work at Manhattan, small average increases have been obtained for the use of superphosphate, potash, and sodium nitrate. The increases have not been large enough, however, to warrant recommending the use of fertilizers very generally in the northeastern part of Kansas.

In the fall of 1926 a new set of tests was inaugurated in order to find if some other method of application might be used that would give higher increases on the wheat crop for the use of superphosphate or mixed fertilizer. The tests herein reported cover three seasons work on this problem. Part of the work is being continued and some additional new phases are being studied. The tests have been made in some of the less fertile areas on the agronomy farm at Manhattan.

PLAN OF EXPERIMENTS

The principal object in these tests was to determine the effect of broadcasting fertilizer over the whole surface and working it into the soil as compared with applying the fertilizer in restricted areas near the seed in the row. Three methods of row applications were used. In one the fertilizer was distributed in the row in direct contact with the seed, in another it was applied about three-fourths inch above the seed, and in a third about three-fourths inch below the seed.

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[1] Contribution No. 189 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication December 4, 1929.

[2] Professor of Soils

Two grades of fertilizer were used, *viz.*, superphosphate (16% P_2O_5) and a 2-12-2. In the latter the nitrogen was supplied in sodium nitrate and the potash in potassium chloride. Each of the fertilizers was used at the rate of 175 pounds per acre.

The plats used in this work were 7 x 12.5 feet or 1/500 acre in area. The rows were 10 inches apart and were made by furrowing out with a wheel hoe. All the planting was done by hand and the seed was planted at approximately 2 bushels an acre.

During the first year each treatment was repeated three times. During the year 1927-28 each treatment was repeated four times. When the two different fertilizers are considered there were double this number of comparisons between row and broadcast applications. In 1928-29 a new series was put out similar to the 1928 tests and the latter tests were repeated on the same land. In 1927 the tests included 30 plats, in 1928 there were 40 plats, and in 1929 a total of 80 plats.

By using a fairly large number of plats and distributing the different treatments over the area, it is believed that variation in soils has been reasonably well accounted for when an average of all plats of a given treatment is taken. The number of plats used is also thought sufficient to eliminate, in part at least, the disadvantage of plats as small as 1/500 acre.

In order to put these results on a more practical basis during the year 1928-29 an additional series was included where the row applications of fertilizer were put on with a fertilizer drill rather than by hand. This was compared with broadcasting.

In this test four replications of each treatment were used. The treatments included broadcast and row applications of both superphosphate and 2-12-2 fertilizer. Every fifth plat was untreated and used as a check. The plats were one drill width, 5 feet 4 inches, and 145 feet in length.

RESULTS

EFFECT ON YIELD OF GRAIN

The results obtained in the small plats have been summarized by averaging the yield for all plats having the same treatment each year. The yields for the different years as well as averages for the three years will be found in Table 1. (See, also, Fig. 1.)

These results show that, while there has been a distinct gain for broadcasting fertilizer over the untreated land, there has been a still further increase from applying the fertilizer in the row with the seed.

TABLE 1.—*Yields in bushels per acre obtained from different methods of applying fertilizer to wheat on hand planted plats.*

Method of application	1927	1928	1929	Second year, 1929*	Average four tests	Increase		Superphosphate over 2–12–2
						Over no treatment	Row over broadcast	
				Superphosphate				
No treatment. . . .	24.69	30.97	15.00	15.86	21.63	——	——	——
Broadcast.	35.24	37.60	22.77	27.04	30.66	9.03	——	1.43
Row	39.86	47.54	29.07	31.64	37.03	16.40	7.37	2.37
Above seed	37.13	44.53	29.06	30.60	35.33	13.70	4.67	0.70
Below seed.	35.73	45.63	27.17	28 49	34.20	12.62	3.59	0.02
				2–12–2 Fertilizer				
No treatment. .	21.23	32.93	14.14	15.40	20.92	——	——	——
Broadcast.	30.72	36.08	22.19	25.09	28.52	7.70	——	——
Row	36.09	45.30	27.68	30.73	34.95	14.03	6.43	——
Above seed. . . .	34.41	42.17	27.73	31.36	33.92	13.00	5.40	——
Below seed	36.30	43.07	26.41	28.29	33.52	12.60	5.00	——

*These plats, on the same land used in the 1928 tests, received a second application of fertilizer.

In most cases the difference between row applications and broadcasting has been about as great as between broadcasting and the untreated land (See Fig. 2.)

The placing of the fertilizer either above or below the seed has not given as good results as where the fertilizer was placed in the row, in direct contact with the seed

The mixed fertilizer 2–12–2 did not give as large increases on this soil as did the superphosphate, although on the whole the differences were not great. That is, the substitution of 2% nitrogen and 2% potash for 4% of phosphoric acid did not appear to be a good practice in these tests.

The significance of these results may be made somewhat clearer by showing the frequency that certain treatments exceeded the yields of others (Table 2).

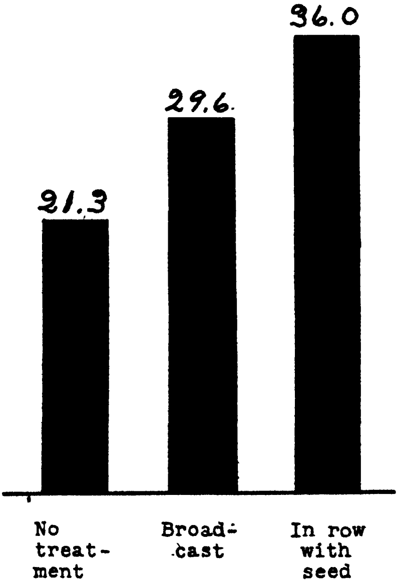

FIG. 1.—Relative yields of wheat in bushels per acre with different methods of applying fertilizers. (Average of superphosphate and 2–12–2 fertilizer.)

TABLE 2.—*Relative effectiveness of different treatments on yield of grain.*

	Superphosphate 15 trials	2–12–2 15 trials	Total of 30 trials	D/E*
Row better than broadcast	15 times	15 times	30 times	8.2
Broadcast better than check	15 times	14 times	29 times	7.5
Row better than above seed	13 times	12 times	25 times	5.5
Row better than below seed	12 times	11 times	23 times	4.4
Above seed better than below	9 times	10 times	19 times	2.2
All rows better than broadcast	39 out of 45 times	42 out of 45 times	81 out of 90 times	11.4
Superphosphate better than 2–12–2			37 out ot 60 times	2.7

*Calculated by the point binomial method as described by Salmon (Jour. Amer. Soc. Agron., 22:77–81. 1930).

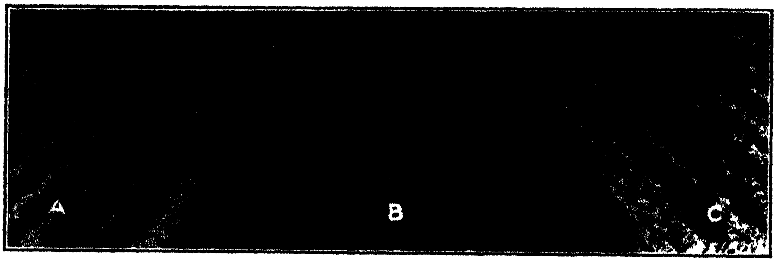

FIG. 2.—Comparison of effect of drilling vs. broadcasting fertilizers on early growth of wheat. A, 2–12–2 fertilizer broadcast; B, superphosphate drilled in row; and C, superphosphate broadcast.

These calculations would indicate that there is little doubt that any of the row applications are better than broadcasting. Also, the application of the fertilizer in the row with the seed seems to be significantly better than either above or below the seed. There would seem to be some question whether the application above the seed is any better than below the seed as D/E is only 2.2 and since a result below 3 is usually taken to indicate that the difference may be due to chance. The fact that the average results show only very little difference in the yields from these two treatments would probably be of even more significance. The advantage of superphosphate over a 2–12–2 fertilizer might also be questioned on the basis of these comparisons. However, the average results for each year show that in every case superphosphate has given a higher yield than the 2–12–2, but the final average is only slightly higher. The comparison of the two fertilizers, superphosphate and 2–12–2, is therefore a minor point in the results of this work. Each has given excellent results and they have indicated that in either case the row application has a decided advantage over broadcast applications.

EFFECT ON STRAW

It is often assumed, particularly in the case of phosphatic fertilizers, that the increase in grain yields will be relatively higher than the increase in straw. The percentage increase in straw calculated from Table 3 shows that superphosphate in the row has increased the yield of straw in these tests by 90%. The increase in yield of grain due to superphosphate calculated from Table 1 was only 75%. This effect of phosphates in producing high increases in straw yields has been shown by the author[3] in other experiments.

TABLE 3.—*Effect on yield of straw in pounds per acre of different methods of applying fertilizers to wheat.**

Method of application	1927	1929	Second year test, 1929†	Average three crops	Increase Over no treatment	Increase Row over broadcasting	Increase Superphosphate over 2-12-2
			Superphosphate				
No treatment...	3.445	3.034	2.593	3.024	—	—	—
Broadcast . .	5,064	4.474	5.081	4.873	1,849	—	423
Row with seed	5,988	5.473	5.835	5.765	2,741	892	389
Row above seed ..	5,640	5.359	6,110	5,703	2,679	830	439
Row below seed.	5.543	5.250	6,069	5.621	2.597	748	408
			2-12-2 Fertilizer				
No treatment	3,249	2,971	2,802	3,007	—	—	—
Broadcast .	4,337	4,014	4.949	4.433	1,426	—	—
Row with seed .	5.342	5.258	5.477	5.359	2,352	926	—
Row above seed	4,825	5,118	5,799	5,247	2.240	814	—
Row below seed	5,224	5,109	5,166	5,196	2,189	763	—

*Straw yield for 1928 lost.

†These plats were on same land as used in 1928.

The plants fertilized in the row were usually about 3 inches taller, and there was considerably more tillering than where the fertilizer was broadcast. Counts made during 1929 in the drill width plats, where the fertilizer was put in with a fertilizer drill as compared with broadcasting, showed that the broadcasting increased the number of culms about 35%, while the row application increased the number about 60%. These figures correspond roughly with the average percentage increase in grain yields as shown in Table 1. It would seem, therefore, that much of the increase in yield due to fertilizer in these tests has been due to an increased number of heads.

DRILL WIDTH PLATS

The results obtained in the drill-width plats during 1929 strongly confirmed the three seasons results obtained in the hand-planted plats. The growth of plants in the fall after seeding showed marked differences in favor of the row applications. The broadcast application also showed some increased growth over the untreated land. The differences in the early spring growth were even more striking and the plats having the fertilizer drilled in with the wheat stood out in striking contrast above the others. The yields obtained are shown in Tables 4 and 5.

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[3] **Duley, F. L.**, and **Miller, M. F.** The soils experiment fields of Missouri. Mo. Ag. Exp. Sta. Bul. 238: 19–20. 1926.

TABLE 4.—*Yields of wheat in bushels per acre from the drill-width plats receiving fertilizer applied broadcast and by drilling.*

	No treatment	Superphosphate Broadcast	Superphosphate Drilled	2-12-2 Fertilizer Broadcast	2-12-2 Fertilizer Drilled
	8.92	16.90	24.13	10.89	22.82
	12.86	9.77*	26.20	18.12	20.75
	13.90	15.21	26.01	14.18	23.94
	8.92	23.00	32.30	16.80	23.50
	14.90				
Ave.	11.90	18.37	27.16	15.00	22.75

*Dead furrow in this plat; omitted from average.

TABLE 5.—*Yields of straw in pounds per acre from the drill-width plats receiving fertilizer applied broadcast and by drilling.*

	No treatment	Superphosphate Broadcast	Superphosphate Drilled	2-12-2 Fertilizer Broadcast	2-12-2 Fertilizer Drilled
	2,845	3,887	5,200	2,727	4,490
	2,665	2,301*	5,470	2,856	4,839
	2,546	3,087	5,481	2,980	4,760
	2,225	3,718	4,940	3,053	4,253
Ave.	2,553	3,564	5,273	2,904	4,585

*Dead furrow in this plat; omitted from average.

These increases in wheat yields obtained by drilling the fertilizer in the row with a fertilizer attachment are not only decidedly higher than the yields obtained by broadcasting, but are so much above previous increases obtained on this land as to leave little doubt as to the value of this method of application.

The effect of the fertilizer in these drill-width tests was very similar to the results obtained in the small hand-planted plats, but there was a greater difference between drilling and broadcasting. This difference seemed to be due mainly to the fact that the increase from broadcasting was somewhat lower than in the hand-planted plats. The increase from drilling was approximately the same as from the row applications made by hand. The yield of the check plats was slightly lower than the series planted by hand. However, there was on the whole reasonably good agreement between the small hand-planted plats and the drill-width plats.

SUMMARY

The relative value of broadcasting fertilizer as compared with drilling in the row with wheat was studied during the years 1926–29 at the Kansas Agricultural Experiment Station at Manhattan. Small plats 1/500 acre in area were used. These were replicated three to four times. The plats were handled by hand. In addition to these, drill-width plats were put in with a fertilizer drill in 1928–29. Comparisons were made here also with broadcasting and with no fertilizer. Superphosphate (16% P_2O_5) was compared with 2-12-2 fertilizer. The mixed fertilizer was made from sodium nitrate, superphosphate, and potassium chloride. The fertilizers were applied in all cases at the rate of 175 pounds per acre.

The results show that the average increase from superphosphate when applied broadcast was 9.03 bushels an acre, while the average increase where the fertilizer was applied in the row with the seed was 16.4 bushels an acre. In other words, there was almost as much difference between row application and broadcasting as between broadcasting and no treatment.

On this soil superphosphate showed slightly greater increases than 2-12-2, when used at the same rate of 175 pounds per acre.

Applying the fertilizer in the row with the seed gave slightly higher yields than when applied either above or below the seed. The results obtained in drill-width plats in 1929 confirmed the results obtained in the small plats 1927–29, showing that under the conditions of these experiments the use of fertilizer in the row with wheat is decidedly superior to broadcasting on yields of both grain and straw.

THE MOISTURE-SAVING EFFICIENCY OF LEVEL TERRACES UNDER SEMI-ARID CONDITIONS[1]

H. H. FINNELL[2]

Studies (3)[3] of the disposition of water on silty clay loam soil under an average annual rainfall of 17.28 inches at Goodwell, Oklahoma, show a small average runoff of 2.33 inches. This may result partly as uneven field distribution and partly as loss from the field into adjacent drainage basins, but there is liability of occasional heavy losses depending mainly on the character of the rainfall.

The relatively low efficiency of the rainfall as a whole, due to slow absorption by heavy soils and to a high rate of evaporation from heat, high winds, and low humidity, places agricultural production very often in an uncertain state. It has been frequently observed that the liberation of plant food in fertile soils outdistanced the moisture supply so that only small or no yields resulted in spite of a fertility condition capable of high production. In such cases apparently small differences in moisture supply have meant comparatively large differences in yields.

Chilcott's (1) conclusion that, "the limitation of crop yield (in the Great Plains area) is most frequently due to the operation of one or of several inhibiting factors other than shortage of rainfall," is perfectly founded, but excites some curiosity as to just what these inhibiting factors may be. It is hard for the Plains farmer to see repeatedly what is manifestly drouth injury to the crops and not send up a cry for more rainfall. Since better use of the same rainfall would have the same effect as an increased amount, it is a pertinent fact that under some conditions as much as four-fifths of the rainfall never reaches the subsurface and subsoils where it may be drawn upon by crops. In such cases additional rainfall is much less needed than agricultural practices which make more efficient use of that which falls.

DISPOSITION OF RAINFALL WATER

The normal disposition of rainfall as calculated from recent experiments (3) on the basis of a 17-year record is shown in the first part of Table 1. A profitable agriculture has been developed under these conditions, but it is generally conceded that a more rapid use could be made of the available fertility of plains soils if additional moisture could be supplied the crops.

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[1] Contribution from the Panhandle Agricultural Experiment Station, Goodwell, Oklahoma. Paper read at the annual meeting of the Society held in Chicago, Ill., November 15, 1929.

[2] Director and Agronomist.

[3] Reference by number is to "Literature Cited," p. 529.

The holding of runoff water in a number of shallow belts across the field to soak into the ground is still far from a complete saving of wastes or a perfect distribution even of the saving, but the results secured from terracing have justified it economically. The redistribution of runoff water has in turn modified the disposition of rainfall by eliminating runoff loss and increasing the amounts soaking into the soil and evaporating from the field.

TABLE 1.—*The disposition of rainfall water on silty clay loam soil under an annual rainfall of 17.28 inches at Goodwell, Okla.*

Disposition	Calculated by	Percentage of total rainfall Unterraced	Percentage of total rainfall Terraced
Enters the soil joining the permanent body of soil water	Direct periodic soil moisture determinations on fallow land	20.7	25.2
Surface runoff	Applying data of experimental rain studies to weather records	13.5	0.0
Surface evaporation of showers too small to penetrate mulch	Applying data of experimental rain studies to weather records	31.3	31.3
Surface evaporation from other rains	Elimination in absence of percolation loss	34.5	43.5

Under the conditions of these experiments with the existing cultural practices, about 20% of the total rainfall becomes soil water available to crop use. With so much room for the improvement of moisture-using efficiency, there is great promise of development along this line in semi-arid regions. Besides this, the advantages of limited rainfall are too great to arouse much legitimate desire for the achievement of any far-reaching climatic modification of the Great Plains, even if it were possible. Freedom from severe erosion and leaching of the soils, freedom from the menace of certain insect pests and diseases, and the advantage of dry harvesting weather are among the greatest agricultural assets of the Plains region.

The first effective move made at the Panhandle Station toward increasing moisture-using efficiency was the construction of level terraces in 1925 for the conservation of runoff water.

An effort was made in 1928 and 1929 to determine by extensive field samplings of fallow soils how much of the terrace-held water soaked in. At the end of the fallow period in 1928 during which the runoff liability amounted to 2.77 inches, the terraced fields contained within the depth of the seasonal water penetration 0.96 inch more water than the unterraced. In 1929, a runoff of 1.16 inches when held back by terraces added 0.40 inch more water to the soil than entered unterraced plats. These two observations agreed very closely, averaging 34.5%, and if it is assumed that they are typical cases, the disposition of rainfall water has been modified by terracing somewhat as shown in the last column of Table 1.

The penetration of terrace-held water, 34.5%, was greater than the average previously determined for the total rainfall under normal conditions, but was less than the highest efficiency observed for a certain period of especially favorable rainfall and temperature conditions in the spring of 1926 (3), during which 39.1% of the rainfall entered the soil. This occurred under a lower than normal rate of evaporation with low soil temperature from rains of ideal size for effectiveness.

The first results of the effects of level terracing on crop yields were obtained from this experiment in 1926. Table 2 gives the data to date. Each plat was 10 acres in size and was laid out checkerboard fashion with naturally drained check plats in an 80-acre field of very uniform silty clay loam soil having an approximately uniform slope of 0.2%. The terraces were built low and broad at 6-inch intervals. The ends were closed and the runoff barred from adjacent land. Owing to the fact that these fields were used for a livestock feed rotation, including summer fallowing and partial utilization of crops by pasturing, it was not possible to get comparative yields from each pair of plats each year, but at least one fair comparison has been obtained each year.

The percentage gains in yield here were not as high as those secured by Dickson (2) at Spur, Texas, but the results of both experiments seem to be in proportional relation to the runoff liability.

Grouping the results on fields cropped the previous year, an average grain equivalent increase per acre of 190 pounds was obtained from the terracing as a 4-year average. Thus, an estimated soil moisture increase of 21.7% gave an actual yield increase of 25.4%. Including the wheat grown in 1929 on summer-fallowed land, the average increase of all observations was 169 pounds per acre with odds 108:1 that this difference did not occur by chance.

TABLE 2.—*Crop yields from unterraced and terraced land at Goodwell, Okla., 1926–29.*

		Yield in pounds per acre		Terrace gain	
Year	Crop grown	Unterraced	Terraced	Pounds per acre	%
1926.....	Milo	637	950	313	49.1
1927.....	Sorghum forage	3,125	4,028	903	28.8
1928.....	Milo	1,343	1,470	127	9.4
1929.....	Wheat	647	742	95	14.6
1929.....	Wheat on fallow	1,777	1,862	85	4.8

FACTORS AFFECTING YIELD RESULTS OF TERRACING

Noting the wide fluctuation in both net yield gains and percentage gains, it is evident that variable conditions affect the service of terraces.

First to consider is the character of rainfall. The terraces will certainly not save any water if there is none going to waste as runoff. The amount saved and the effect on yields, in so far as moisture may happen to be a limiting factor, are also bound to vary according to the amount of excessive rain received This is indicated by the observations at both Spur and Goodwell.

The period of this experiment is shown in Table 3 to average 2.46 inches of runoff annually This is very near to the average of 2.33 inches runoff liability as calculated from the records of the 17-year period.

TABLE 3.—*Runoff liability on silty clay loam soil at Goodwell, Okla., 1926–29.**

Date and runoff in inches							
1926		1927		1928		1929	
June 18	0.17	July 10	0.01	Feb 6	0.02	Mar. 28	0.89
June 25	0.46	July 23	0.48	May 3	0.17	May 1	0.13
June 26	0.75	July 29	0.65	May 11	0.60	July 8	0.03
Sept. 5	0.41	Aug. 4	0.12	May 13	0.41	July 9	1.28
		Aug. 29	0.28	May 14	0.54	July 10	0.28
				June 3	0.36	Aug. 28	1.16
				July 21	0.24		
				Oct. 13	0.43		
Total annual	1.79		1.54		2.77		3.77
Total crop years, harvest to harvest	1.79		1.54		2.77		4.44
Total growing season	1.79		1.54		1.03		1.02

*Runoff liability as used here indicates the quantity of water in danger of loss by runoff due to having fallen after the surface movement of water begins on shallow mulched silty clay loam soil with an average slope of less than 1%. The variability in amounts of water leaving a field depends so much on uneven topography, natural outlets, basins, size of the field, and cultural conditions that exact losses can not be estimated for extensive areas. This method of estimating runoff liability from rainfall data has been shown to check closely with the actual amount of water leaving a plat 350 feet long with a uniform slope of 0.7%.

The amount of runoff saved during the growing period seems to be most highly significant. Though the limited data are not so well adapted to analysis by correlation, the complete calculations of the associations in Table 4 are appended as Table 5.

The runoff occurring outside the growing season has little apparent relation to crop yields, except through initial soil moisture, as excessive rains may have been associated with plentiful effective rainfall.

High yields of crops secured by the use of advance stores of soil water are shown in Table 4 to be associated with low percentage gains in the absence of stringent moisture limitations. High yield is not so strongly related to low absolute yield gains from terracing. It is probable that the yield-increasing function of terrace saved water at Goodwell depends chiefly on the time of excessive rains and the service of terraces in turn on the amount of excessive rains.

TABLE 4.—*Factors relating to terrace service at Goodwell, Okla., 1926–29.*

Year	Growing season runoff liability (A)	Initial soil water % (B)	Pound per acre grain basis, unterraced (C)	Increased yield on terraced land: Pounds per acre (Z)	Increased yield on terraced land: % (X)
1926	1.79	14.79	637	313	49.1
1927 . . .	1.54	13.27	781	225	28.8
1928 . . .	1.03	17.09	1,343	127	9.4
1929	1.02	16.72	647	95	14.6
1929 . . .	1.02	19.96	1,777	85	4.8
Means.	1.28	16.36	1,037	169	21.3
σ				87.5	

TABLE 5.—*Correlation of factors relating to terrace service as in Table 4.*

	A	B	C	Z	Beta Z
A—Runoff	1.0000	—0.7601	—0.5988	0.9858	0.9704
B—Initial soil moisture		1.0000	0.8064	—0.7588	—0.0202
C—Yield.			1.0000	—0.5992	—0.0028
				—R_{abcz}	0.9867
R, corrected for small number of observations					0.9682

	A	B	C	X	Beta X
A—Runoff . .	1.0000	—0.7601	—0.5988	0.9659	0.9623
B—Initial soil moisture		1.0000	0.8064	—0.7436	0.3094
C—Yield			1.0000	—0.7254	—0.3987
				R_{abcx}	0.9943
R, corrected for small number of observations					0.9857

If the results of four years may serve as a pointer, it is evident that the percentage expression of yield increases due to terrace conservation of moisture is misleading from the viewpoint of economic returns when compared with the actual gains made. The absolute yield gains also constitute the best criterion of the efficiency of terrace-held water during the growing season, considering the purity of the relationship existing.

TERRACE SPACING

It is not known whether or not the terrace spacing used (6-inch level steps on 0.2% slope) is the most efficient. The loss of moisture at depths beyond reach of the wheat roots when terraced land was summer fallowed in 1928 shows that more belts of water concentration were needed. On the other hand, a study of soil moisture in fields cropped every year suggests that the spacing used was closer than necessary. This may mean that summer fallowing is incompatible with terracing for moisture conservation under the conditions represented, if fallowing is an unnecessary duplication of effort.

There are certainly a number of considerations which reasonably may have a bearing on the spacing The following are suggested: The normal amount of available water carried by the soil through the non-growing season; the rooting depth of the crop grown; the number of excessive rains expected; the maximum amount of runoff expected at any one time; the soil wetting efficiency of rainfall and of terrace-held water; the water-holding capacity of the soil; and the slope of the land

The numerical values of these factors must be determined by observation, survey, or experiment for each locality before they can be used as a basis of estimate for terrace spacing Much of the data is already available in other connections and needs only to be adapted for this purpose. Where so many factors are involved it becomes almost necessary to use a mathematical expression of the problem, although it should be clearly understood that little of mathematical accuracy can be expected except by viewing the values arrived at in the light of means with considerable ranges of fluctuation Many of the primary values used have very high probable errors. However, in spite of this, such a formula should help considerably to eliminate pure guesswork in appraising the possibilities of profit from saving runoff water and in laying out new experiments in terrace spacing.

The principle involved is that where terraces are needed for moisture conservation they should be so spaced that the maximum water concentration does not penetrate beyond the rooting depth of the crop grown. The purpose of adopting this limitation is to prevent the waste of water and plant food and in so doing a maximum width of terraces is established below which the best efficiency exists. A very clear expression on this point has been made by Shantz (4), a conception which has been borne out by studies at this and other stations.

The maximum depth of water permissible on the terrace at one time, L, was used as a constant expressive of the climatic and soil water relations peculiar to a certain locality and soil type because it may be used for more than one purpose. If this depth of water is known within reasonable limits, it can be used as an index number to determine the advisability of terracing for moisture saving and the size of terraces to use as well as the basis for calculating the proper distance between terraces on different slopes. A suggested method of estimating the value of L is as follows: $\frac{C\,D - A\,F\,P}{F_1E} = L$, where C represents the water-holding capacity of the soil in inches of plant-available water per foot of soil; D, the rooting depth of the crop grown in feet; A, the average annual rainfall in inches; F, the penetrating efficiency of the annual rainfall as percentage entering the soil; P, the percentage of total rainfall coming outside the growing season; F_1, the penetrating efficiency of terrace-held water as percentage entering the soil; and E, the average number of excessive rains received annually.

In the use of this formula it is assumed that the growth of crops in the growing season is able to take care of excessive moisture entering the soil at that time with much less risk of waste than when no crops are on the field. The spacing of terraces, therefore, is more concerned with the proper distribution of water accumulating during the preparatory period when wastes are more likely to occur. A factor of safety may be provided by preparing to utilize the average number of excessive rains should they all fall outside the growing season and each be of the maximum size expected.

It is apparent at this point that the calculations are entering the field of speculation to a certain extent, and it is very likely several other as good or better assumptions could be substituted. Whatever method of estimating the factor L is used, the limit of terrace width would be calculated as $\frac{L^2}{2\,S\,A_1}$, with S representing the percentage slope of the land or matured terrace and A_1 the maximum runoff expected at one time.

When L is greater than zero, there exists a certain soil capacity to hold more water for crop use than normally is received during the preparatory period. If runoff occurs, the saving of it by terracing enables the increase of moisture supplied to crops. When L is equal or nearly equal to zero, the soil would normally carry a full supply of moisture into the growing season, and the use of terraces could not increase the amount of initial moisture available to crops. When L is less than zero, excessive soil moisture prevails and drainage becomes the problem rather than the saving of more water for crop use.

In any case where soil moisture deficiency is indicated by a capacity to utilize considerable additional amounts of water in the presence of excessive runoff, the ability of terraces to make up the entire wants of the crop may be limited either by soil capacity or the time of the occurrence of runoff.

In either of the cases where the desirability of saving runoff water by terracing was not indicated, terraces installed for the control of erosion only should also be of service in moisture saving under occassional abnormal conditions.

If, under conditions requiring the use of runoff water, a terrace spacing too close for operative practicability is necessary to prevent loss of water below the root zone, the method resolves itself into contour tillage with possibly a system of safety terraces.

DISCUSSION

The use of terracing to utilize 2.33 inches of runoff water annually, which, when held on terraces, has a penetrating efficiency of 34.5%, increased the annual supply of soil water from 3.58 to 4.38 inches. This is only about half the water-holding capacity of silty clay loam soil to a depth of 6 feet. When the maximum efficiency of saving runoff water has been reached there is still use for any other method of culture or farm practice that will hasten absorption for the lessening of the enormous evaporation loss.

Under the particular conditions of these experiments the question of the economy of summer fallowing has been unsettled. It may be that the advent of terracing will push the border area subject to fallowing further toward the drier regions.

Although the validity of some of the assumptions used in the formula presented is questionable, the principle of distributing saved runoff water at intervals insuring its full productive usefulness is thought to be basic.

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THE USE OF SMALL AMOUNTS OF LIME IN THE ROW[1]

M. M. McCool[2]

Attention was called to the possibility of the use of small amounts of lime applied in the row with clover and alfalfa seed and data cited by the author in the February, 1927, issue of this Journal. Certain of the tests which were in progress at that time, and additional ones, have been continued. Soil types which vary widely in their response to lime are included in these trials. A conservative interpretation of the results obtained to date makes it possible to say that this practice appears to have possibilities in reducing the labor and capital costs of liming, under certain conditions.

When these experiments or tests were planned, the problem appeared to be relatively simple, but, as with most projects, it rapidly became complex. According to reports by numerous investigators, when we deal with the H-ion concentration of the soil, we are considering something that is dynamic. Hopkins (1)[3] several years ago referred to this when he stated that, "about one-half the water that falls in rain and soaks into the soil is brought back to the surface from lower depths by capillary action. More or less acidity is thus brought up from the acid subsoil, especially in time of drought."

Gardner and Brown (2) reported results which showed the lime requirement of certain Pennsylvania soil fertility plats to change as much as 1,040 pounds per acre during the period from June 15 to August 15. They found the acid soil to be more acid in August than in June.

Several workers have obtained data which show the pH of soils under field conditions to change somewhat from spring to autumn. A summary of the results obtained by several investigators appears in Table 1.

Table 1.—*Change of pH of field soils as found by different investigators.*

Investigators		pH change	Period
Lipman, *et al.*	(3)	0.7	May–November
Erdman	(4)	0.35	March–August
Mather	(5)	0.7	May-July
Kelley	(6)	1.0	1 year
Kurz	(7)	1.0	1 year
Burd and Martin	(8)	0.2–0.6	April–September
Burgess	(9)	0.2–0.6	May–September
Baver	(10)	0.2–0.5	April–June 1924
		0.09–0.18	April–September 1925
Aarnio	(11)	0.83–1.04	January–October

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[1] Contribution from the Soils Department, Michigan State College, East Lansing, Michigan. Journal Article No. 129 (N. S.). Paper read at the annual meeting of the Society held in Chicago, Ill., November 15, 1929.

[2] Professor of Soils.

[3] Reference by number is to "Literature Cited," p. 536.

Remezov, cited by Himmerline (12), carried on experiments in 1924 and 1925 near Moscow, Russia, and found, in brief, that the H-ion concentration of the podsol soil varied as much as unity over rather short intervals of time. In 1924, the pH of the soil in question was low, as the water content was low, and increased as the water content became higher. On the other hand, no such relationship existed the following year. During the progress of soil surveys in Michigan, it has been observed repeatedly that the reaction of some soil types varies somewhat from time to time, whereas others vary but slightly in this respect.

Samples of some soil types, moreover, when taken into the laboratory and permitted to become air-dry change considerably in their H-ion concentration. According to the results of certain investigators, it appears that neutral or alkaline soils change more in this respect than do those that are acid in reaction. Christenson (13) found silt soils to be considerably less acid when wet than when in the air-dry and powdered condition The greatest changes were observed to take place in the alkaline soil Burgess (9) and Rost and Fieger (14) found similar relationships.

Baver (10) did not find any significant changes in the H-ion concentration of Wooster silt loam upon drying, that is, the acid surface layer. However, where lime had been applied in sufficient amounts to bring about an alkaline reaction, the H-ion concentration increased markedly upon air-drying as did the alkaline subsoil horizon. Cook a short time ago observed the changes upon air-drying in the A and B horizons of six soil types in the vicinity of East Lansing, Mich.

TABLE 2.—*The effect of air-drying on the pH of soils.*

Soil	Horizon	pH moist	pH dry	Differences
Plainfield	A	5.80	5.64	0.16
Plainfield	B	5.58	5.58	0.0
Brookston	A	6.73	6.60	0.13
Brookston	B	7.28	7.15	0.13
Miami	A_2	5.87	5.60	0.27
Miami	B	5.84	5.84	0.0
Miami	B_3	8.21	8.08	0.13
Hillsdale	A	6.22	6.19	0.02
Hillsdale	B	5.67	5.29	0.38
Newton	A	6.01	5.88	0.13
Newton	B	6.20	5.90	0.30
Coloma	A	5.87	5.04	0.83
Coloma	B	5.62	5.25	0.37

The data presented in Table 2 show a general tendency for the acidity, as determined by the hydroquinone method, to become greater upon air-drying. The pH of the B horizon of three of the soil types changed more than did the A horizon, whereas the reverse was true of two of them, and no difference was found between horizons in the other one. It is evident, therefore, that the nature of the soil enters into this phenomenon.

The increase in the H-ion concentration of field soils from spring to autumn, for example, may be due in part to an increase in the soluble salt content. The removal of soluble salts by leaching from soils decreases the H-ion concentration. The changes upon air-drying of the samples reported may have been due to alterations of the surface exposure of the soil particles or groups of them. If the structure were changed upon air-drying, it is possible to conceive of the exposure of new surfaces, thus altering these relationships somewhat.

Still another point of interest which may have a direct application to this problem is the variation of the rate at which coarse particles of limestone break down and disappear when applied to different soil types. Field studies by G. M. Grantham, who is in charge of the soil fertility investigations of the western half of Michigan, have revealed the Warsaw type to be very active in the decomposition of limestone. When coarse limestone was applied to it in November, all the particles had disappeared by the next November except the largest ones, and these were reduced in size and were broken down into finely divided material when attempts were made to remove them from the soil. When the same limestone, however, is applied to Coloma sand, for example, the particles disappear at a much slower rate. It is apparent that the amount and the activity of the organic matter present in the soil is an important factor in governing the rate at which the particles of limestone break down.

It appears furthermore that the depth to which carbonates have been removed from the soil by weathering is to be considered in the results obtained from the use of lime on the land. There are reports on record which indicate that smaller applications of lime are required for alfalfa on soils where the carbonate lies near the surface than where it occurs at greater depths. It is well known that legumes thrive on some soils whose H-ion concentration is greater than that of some soils upon which applications of lime are necessary for their growth, and, finally, it does not appear to be necessary to bring the soil reaction to neutrality for the successful inoculation and production of these crops.

There is also the factor of inoculation. It is probable that the beneficial results which follow applications of lime to some soils when seeded to legumes is due, in part, to changes induced which are favorable for the growth and development of the bacteria with which the seed have been inoculated.

The author has also observed that clover and alfalfa seed germinate in the greenhouse and under field conditions on unlimed soils but damp off soon thereafter. This is largely prevented by the addition of lime to the soil.

The outstanding soil fertility problem in Michigan is the production of legumes for soil improvement. Much of the land under cultivation needs lime for the production of soil-improving crops, such as clovers and alfalfa. Many farmers do not follow a satisfactory crop sequence on much of their land, owing to the labor and capital costs involved in applying the quantities of lime which are needed in ordinary practice. Potato growers, moreover, in certain sections of the state find it advisable to follow alfalfa or sweet clover with potatoes. In fact, a majority of the certified seed growers follow this practice. It is necessary to lime these soils in order to establish the legumes. However, lime must be used judiciously, according to reports, otherwise the potato tubers are infected by the scab-producing organism At the present time, we are not greatly concerned over the alfalfa fields near the farmstead, but the big problem is to bring about changes in the management of land where legumes are not being grown

The possibility of reducing the amount of lime necessary to produce these legumes by localizing the lime in the soil near the seed was brought to our attention by a consideration of these conditions. Accordingly, as previously reported in this JOURNAL, field trials with alfalfa were inaugurated in 1923. Several projects have been laid out since that time. In some of these projects different carriers of lime have been used In others, lime has been placed in different positions with respect to the seed, or with and below the seed. Where the experiments were carried out by the small plat method, the lime was applied by hand or by a garden seed drill with fertilizer attachment. In other experiments the grain drill with grass seeder attachment was used in drilling the seed and applying the lime in the row. The seed and lime were sown through the same tubes thus placing them in contact or in close proximity to each other in the soil. The drills we have used are capable of depositing about 650 pounds of medium finely ground limestone or 400 pounds of finely ground or 250 pounds of hydrated lime per acre.

The results obtained from various soil types differ widely. Several failed, whereas others were successful. The Isabella sandy loam soil type occurs extensively in the central part of the southern peninsula. It lies in the podsol group of soils. In the older settled sections, clover and alfalfa as a rule fail unless lime is added to the soil. In the spring of 1928 a 14-acre field was seeded to sweet clover. On 12 acres of this field, 600 pounds per acre of medium finely ground limestone were drilled into the ground with the seed. On 2 acres, 230 pounds of hydrated lime were drilled with the seed. On the 12-acre section the results were satisfactory and an excellent crop of clover was obtained. Where the hydrated lime was applied on the 2 acres and where no applications of lime were made, the crop failed. The customary practice in this section is to apply broadcast 2½ to 3 tons of limestone per acre.

The row method of application was compared with the broadcast method on a large scale on another field. Here comparisons were made between 3 tons broadcast, 552 pounds drilled, and no application. The applications were made in triplicate, lengthwise of the field, making the strips approximately 57 rods long. From Figs. 1 and 2 it would appear that the application of 552 pounds of limestone in the row was as satisfactory for sweet clover and alfalfa as 3 tons of limestone broadcasted.

While on the International Soil Science Congress Tour, the author met P. M. Poirot of the Poirot Farms near Golden City, Missouri. He had become interested in the practice of applying lime in the row with legumes after reading the note on this practice to which reference has been made. At his request, we offered suggestions for trials on his farm. On October 22, 1929, a letter was received from him from which the following is a quotation.

> "I followed your suggestion made during your visit on the 'soils special' a few years ago and also your suggestions in a letter of Nov. 11, 1927. They were as you may recall to use the No. 30 lime at 300 pounds and 500 pounds per acre with inoculated soil and with the regular cultures. I did this, using 100, 300, and 500 pounds each in three plats having regular cultures, regular cultures at five times their ordinary rates of application, and soil from a clover field. The plats on which the soil was used received 200 pounds per acre mixed with the lime and drilled through the fertilizer attachment on the drill. The seed was sown through the seeder attachment. Where the lime was drilled alone, it was drilled the same way.
>
> "In each of the different applications of lime, the soil gave the best results with exceptional inoculation. The 300 pounds of lime and 200 pounds soil was much better than any of the others, and better than where 2½ tons of No. 10 stone had been used.
>
> "As a farmer, of course, I am not interested so much as to why a thing may happen, but interested in making the thing happen at a small cost and with the same results each time. This, I believe may be expected from the No. 30 lime 300 pounds and soil 150 pounds, for it has not failed up to the present time. We put in 30 acres this way last spring and will put in 100 acres like it next spring. In each case,

we used a clover mixture of sweet and red. The red seems to respond some better, but this year, with a very dry summer, both are good."

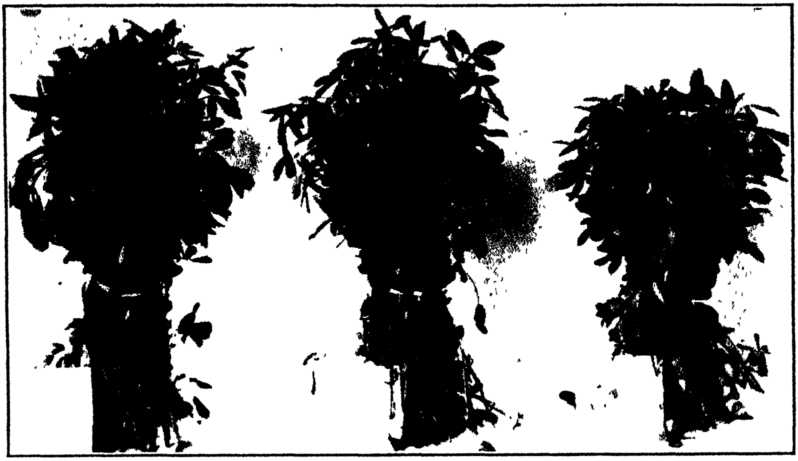

FIG. 1.—Comparative growth of sweet clover following various applications of limestone. 1, 3 tons of medium finely ground limestone per acre broadcasted; 2, 552 pounds of medium finely ground limestone per acre drilled in the row with the seed; and 3, no lime.

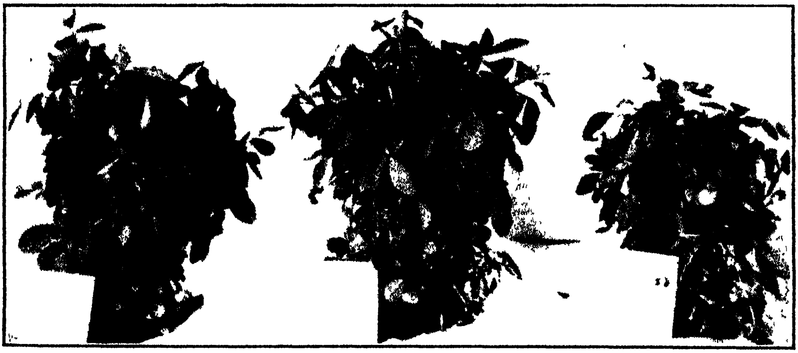

FIG. 2.—Comparative growth of alfalfa following various applications of limestone. 1, 3 tons of medium finely ground limestone per acre broadcasted; 2, 552 pounds of finely ground limestone per acre drilled in the row; and 3, no lime.

In conclusion, it should be stated that we have taken a conservative attitude with respect to putting this procedure into practice because not all soils respond to the same degree to this method. Upon further investigation it may be possible to throw several soil types into a group on which the use of small amounts of lime in the row with the legume seed will be successful.

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ACTIVATED SLUDGE AS A FERTILIZER FOR COTTON AND CORN[1]

E. B. REYNOLDS[2]

The proper utilization of sewage to conserve the large amounts of nitrogen, phosphoric acid, and potash which it contains is of tremendous potential importance to agriculture. Many municipalities in America, England, and Europe have given much attention to the matter in recent years. A great deal of work has been done in the chemical, biological, and engineering phases of the problem. Less attention, however, has been given to actual field trials of sewage and sewage sludge to determine the value of the materials in increasing the yield of crops

Recently, Noer[3] at the University of Wisconsin made a study of activated sludge as a fertilizer for various crops. He found that the nitrogen in activated sludge was as readily available to plants as was the nitrogen in cottonseed meal or fertilizer tankage. Activated sludge was a good source of nitrogen for cabbage, corn, potatoes, and tomatoes. In the field experiment with cabbage, fertilizer mixtures were used having the analysis of 4-10-6 in which activated sludge, sulfate of ammonia, and tankage alone and in combinations with nitrate of soda formed the sources of nitrogen. Activated sludge was a better source of nitrogen than sulfate of ammonia or tankage. The fertilizer in which activated sludge was the only source of nitrogen produced 13.45 tons of cabbage per acre, as compared with a yield of 13.85 tons per acre obtained from the fertilizer in which one-half of the nitrogen was in the form of activated sludge, one-fourth in sulfate of ammonia, and one-fourth in nitrate of soda. Activated sludge was a good fertilizer for lawns and golf courses

In 1924, the Texas Agricultural Experiment Station began field experiments to determine the value of activated sludge as a fertilizer. There had been no previous work announced on the rate of application of activated sludge. In these experiments the sludge was applied at the rates of 500, 1,000, 1,500, and 2,000 pounds per acre. These amounts of sludge contain about the same amounts of nitrogen as 100, 200, 300, and 400 pounds of sulfate of ammonia, respectively.

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[1] Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 85. Received for publication December 13, 1929.

[2] Chief, Division of Agronomy.

[3] NOER, O. J. Activated sludge: Its production, composition, and value as a fertilizer. Jour. Amer. Soc. Agron., 18: 953-962. 1926.

Superphosphate also was used alone at the rate of 200 pounds per acre and in combination with 1,000 pounds of sludge. The sludge, obtained from the city of Houston, Texas, contained 4.6% nitrogen and 2% phosphoric acid (P_2O_5). The sludge was applied broadcast to the land before planting and disked in to mix well with the soil. All of the treatments were made in duplicate. The work was conducted on the main station farm at College Station, and at Substation No. 3, Angleton, Texas. The experiment at College Station was located on Lufkin fine sandy loam, an ashy gray soil with a gray or mottled grayish and yellow plastic subsoil. This soil is low in organic matter, nitrogen, and phosphoric acid. The soil at Angleton is classified as Lake Charles clay loam which is somewhat deficient in phosphoric acid and usually responds to applications of phosphatic fertilizers.

TABLE 1.—*The effect of activated sludge on the yield of cotton and corn.*

Treatment	Pounds per acre of lint cotton at College Station	Angleton	Bushels per acre of corn at Angleton
None	247	244	15.8
500 pounds sludge	288	256	16.1
200 pounds superphosphate	291	264	17.4
1,000 pounds sludge	284	276	18.2
1,000 pounds sludge 200 pounds superphosphate	285	298	20.0
1,500 pounds sludge	294	295	18.6
2,000 pounds sludge	289	308	19.0

Cotton and corn were used in the experiment. All of the treatments of sludge at College Station increased the yield of cotton, the increases ranging from 37 to 47 pounds of lint per acre (Table 1). The combination of 200 pounds of superphosphate and 1,000 pounds of sludge did not produce a larger yield of cotton than the superphosphate or sludge alone. At Angleton, the yield of cotton increased as the amount of sludge was increased. The first increment of 500 pounds of sludge increased the yield of lint cotton 12 pounds; the second increment, 20 pounds; the third increment, 19 pounds; and the fourth increment, 13 pounds per acre. The 200 pounds of superphosphate increased the yield of cotton 20 pounds per acre. Where the superphosphate was used with 1,000 pounds of sludge, the yield of lint was 298 pounds per acre, or 22 pounds more than the yield resulting from the application of 1,000 pounds of sludge alone. On the average, the treatments of sludge increased the yield of cotton 17% at College Station and 16.4% at Angleton. The sludge increased the yield of corn 13.9%, although the actual increase in bushels per acre was small.

Sludge applied at the rate of 1,000 pounds per acre increased the yield of cotton 37 pounds per acre at College Station and 32 pounds per acre at Angleton. If the cotton (lint) is valued at 18 cents a pound, these increases in yield are worth $5.76 to $6.16 per acre. On this basis the sludge would have a value of $10.00 to $12.00 a ton. The farmer, however, could not afford to pay $12.00 a ton for the material as a fertilizer for cotton for the reason that transportation charges and cost of applying the material should be deducted.

EFFECT OF IRRIGATION WITH SEWAGE EFFLUENT ON THE YIELDS AND ESTABLISHMENT OF NAPIER GRASS AND JAPANESE CANE[1]

W. E. Stokes, W. A. Leukel, and R. M. Barnette[2]

Due to higher temperatures during the course of the year and to the type of soil developed under these climatic conditions, the establishment of a perennial forage crop in Florida presents a different problem from that in northern portions of the United States. The limiting factor for the establishment of a perennial forage crop under Florida conditions appears to be the distribution of rainfall as related to nitrogen utilization. An experiment using sewage effluent for irrigation purposes afforded an opportunity to study the establishment of such forage crops under Florida conditions.

In February 1922, a cooperative agreement was entered upon between the Florida Agricultural Experiment Station and the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Dept. of Agriculture, for the purpose of studying the use of sewage effluent for the fertilization of forage crops. For this purpose, eight plats of Japanese cane (*Saccharum officinarum*) and eight plats of Napier grass (*Pennisetum purpureum*) were established in February 1922. Each plat consisted of six rows, 6 feet apart on a gradual sloping area of Norfolk fine sandy soil (deep phase). Four of eight plats in each case were used for irrigation purposes, the remaining four plats receiving no irrigation.

The sewage effluent used for irrigation was obtained from the septic tanks employed at the time for sewage disposal at the University of Florida. The receiving tank for the effluent was placed outside the plats at their lower level. The effluent was pumped to the higher border of the plats through a pipe line and a valve system installed for distribution. The valves were so arranged that the effluent flowed by gravity down the four middles of the six rows of Japanese cane or Napier grass in each irrigated plat. Each irrigated plat received a 24-hour flow of this effluent every eight days from early spring until late fall or until the harvest of the crops, except during the vacation periods of the University. In 1924 and 1925, a three-row plat of unirrigated Napier grass was used to study the effect of irrigation with city water.

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[1] Contribution from the Agronomy Department of the Florida Agricultural Experiment Station, Gainesville, Florida, in cooperation with the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Dept. of Agriculture. Published with the approval of the Director of the Florida Experiment Station and the Chief of the Division of Agricultural Engineering, Bureau of Public Roads. Received for publication December 16, 1929.

[2] Agronomist, Associate Agronomist, and Associate Chemist, respectively.

The Napier grass and Japanese cane were cultivated during the early part of the growing season so as to remove all weed growth, to establish a bed for the effective flow of the water, and to insure a better utilization of the effluent by the forage plants.

The effluent was used for irrigation purposes from the spring of 1922 until the fall of 1925, at which time the plant was dismantled. However, the Napier grass was continued in culture until the fall of 1928 in order to ascertain the effects of the irrigation with sewage effluent upon the subsequent growth of the grass

COMPARATIVE YIELDS OF SILAGE

A single harvest of the Japanese cane was made each season in late fall when the cane was suitable for silage Two cuttings of the Napier grass were made during the season at a stage of growth best suited for silage purposes. The yields of Japanese cane and Napier grass were obtained from the four inner rows of the irrigated and non-irrigated plats. The area of the inner four rows harvested was adjusted so as to give a representative yield for the plat. The yields for each season from 1922 to 1927 inclusive were calculated in terms of tons of silage per acre. The results are given in Table 1.

TABLE 1.—*Yield in tons per acre of Napier grass and Japanese cane silage from irrigated and non-irrigated areas, and yield of Napier grass silage after sewage irrigation was discontinued.*

	Napier grass			Japanese cane	
Year	Irrigated with sewage	Not irrigated	Irrigated with city water	Irrigated with sewage	Not irrigated
		During Irrigation			
1922	28.28	15.79	——	29.45	19.02
1923. ...	42.43	21.61	——	34.97	21.78
1924.	39.54	14.08	20.34	15.86	9.33
1925.	52.02	19.09	17.37	23.31	11.59
Average ...	40.57	17.64	18.86	25.89	15.43
		Irrigation Discontinued			
1926......	12.90*	4.59	——	——	——
1927......	55.44	14.56	——	——	——

*Only one cutting made during season.

During the years 1922 to 1925 inclusive when the sewage was applied, the average tonnage of Napier grass silage from the sewage-irrigated areas was 40.57 tons per acre as compared with 17.64 tons per acre from the non-irrigated plats. The average silage tonnage from the plat irrigated with city water during 1924–25 was 18.86 tons per acre as compared with 16.59 tons per acre from the non-irrigated area during the same period. The average yield of silage from the irrigated plats for this period was 45.78 tons per acre. The yields of Napier grass silage from the irrigated and non-irrigated plats after the sewage irrigation was discontinued in 1925 show that the irrigation had a distinct after effect. The yields from the plats previously irrigated with sewage were, on an average, 3.3 times as large as those obtained from the non-irrigated areas. No yields were calculated for the 1928 season; however, the beneficial effects of the previous irrigation with sewage were apparent from the larger stand on the irrigated plats.

The average tonnage of Japanese cane silage from the irrigated plats for 1922-25 inclusive during the time of irrigation with sewage effluent was 25.89 tons per acre as compared with 15.43 tons per acre from the non-irrigated plats. After 1925, the Japanese cane experiment was discontinued.

There was a marked increase in tonnage of silage of Napier grass and Japanese cane from the plats irrigated with sewage over that from those not irrigated during 1922-25 inclusive. There was no marked increase in yield of silage of Napier grass from the plat irrigated with city water over that from plats receiving no irrigation. Since the yields from the plat irrigated with city water showed only a slight increase over those from the non-irrigated plats, then the greatly increased yields from the sewage-irrigated plats must not be due to an increased water supply alone. The plant nutrient materials supplied by the sewage effluent, together with the increased water supply, were apparently effective in bringing about the increased yields during the period that the plants were irrigated with this effluent. A typical analysis of the sewage effluent is given in Table 2.

TABLE 2.—*Typical analysis of sewage effluent used for irrigation purposes, sample collected January 8, 1926.**

Nitrates: None
Nitrites: 1.21 p.p.m.
Free NH_3: 27.31 p.p.m.
Albuminoid NH_3: 5.32 p.p.m.
Total solids: Original; 266 p.p.m.
Filtered; 125 p.p.m.

P_2O_5: 8.2 p.p.m.
CaO: 41.9 p.p.m.
MgO: 19.2 p.p.m.

*Analyses made on original sewage effluent except where indicated.

SEWAGE ANALYSIS

From the analysis given in Table 2, it may be seen that the nitrogen content of the sewage is relatively high and that the effluent in addition contains a number of nutrient elements, i.e., CaO, P_2O_5, and MgO, in considerable quantities.

SOIL ANALYSIS

After the irrigation with sewage effluent was discontinued in November, 1925, soil samples were taken from the irrigated and non-irrigated plats and prepared for analysis. The loss on ignition was used as a measure of the organic matter content of the soil. Total nitrogen was determined by the Kjeldahl method and P_2O_5 by the $Mg(NO_3)_2$ method. The replaceable CaO and MgO were determined by replacing these bases with NH_4 of a N NH_4Cl solution. The H-ion concentration was determined with a wedge colorimetric outfit using a clear soil extract. Table 3 gives the averaged analyses of the samples taken from the effluent-irrigated and non-irrigated plats of Napier grass and Japanese cane.

TABLE 3.—*Averaged analyses of soils from effluent-irrigated and non-irrigated plats of Napier grass and Japanese cane.*

	Depth in inches					
	Non-irrigated			Irrigated		
	0–6	6–12	12–18	0–6	6–12	12–18
Loss on ignition, %	1.75	1.47	1.27	2.03	1.49	1.29
Pounds per acre*	35,000	29,400	25,400	40,600	29,800	25,800
Nitrogen, %	0.0408	0.0273	0.0169	0.0444	0.0289	0.0203
Pounds per acre*	816	546	338	888	578	406
P_2O_5†, %	0.210	0.187	0.206	0.220	0.200	0.193
Pounds per acre*	4,200	3,940	4,120	4,400	4,000	3,860
Replaceable CaO, %	0.049	0.046	0.038	0.074	0.057	0.051
Replaceable MgO, %	0.021	0.021	0.021	0.027	0.023	0.021
pH	6.33	6.29	6.33	6.34	6.34	6.32

*On the basis of 2,000,000 pounds per acre 6 inches.
†Analysis made on Napier grass plats only.

An increase of 6,400 pounds of organic matter and 172 pounds of nitrogen per acre 18 inches was observed for the effluent-irrigated plats over that of those receiving no such irrigation. No increase in P_2O_5 was noted, while the percentages of replaceable CaO and MgO were increased by the irrigation with sewage effluent. The pH value of the soil remained the same. Thus irrigation with sewage effluent has increased somewhat the total nutrient supply of the soil for plant growth.

ORGANIC FOOD RESERVES

Although a slight increase is noted in the soil fertility of the sewage-irrigated plats over that of those not irrigated, this difference in fertility alone does not account for the outstanding increase in tonnage yields of Napier grass silage from the irrigated plats after irrigation was discontinued. Thus an explanation for this difference in silage yields after irrigation was discontinued was attempted from the standpoint of increased accumulation of plant foods in the subterranean storage organs of the plants themselves. It seems reasonable to assume that with an increased supply of nitrogen and moisture) as was furnished by the sewage effluent) an increase in the production of top growth (increased silage yields) would result. The greater leaf area on such top growth naturally would result in the elaboration of organic foods far in excess of the growing needs of the plants, which foods are in turn translocated to the lower storage organs of the plant. This would result in an increased growth of these storage organs and a larger supply of organic foods for future growth stored therein.

A study was made to determine whether such an increased elaboration and storage of organic foods in the storage parts of the plants in the sewage-irrigated plats was a factor in bringing about the increased silage yields. Samples of crowns and roots of Napier grass from the irrigated and non-irrigated plats were taken sometime before spring top growth started in 1926 to 1929 inclusive. These samples consisted of the crowns and roots of such plants from an area of 60 square feet or 10 feet of row. These samples were rapidly dried and prepared by methods described by Leukel.[3]

TABLE 4.—*Average percentage of dry matter, sugars, and higher carbohydrates in crowns and roots of Napier grass dug previous to the production of spring top growth for the years 1926 to 1929, inclusive.**

Compound	Irrigated with sewage effluent		Not irrigated	
	Crowns	Roots	Crowns	Roots
Dry matter	27.750	49.600	26.550	49.825
Reducing sugar	3.513	1.688	3.452	2.067
Total sugar	4.811	4.113	4.630	4.083
Starches, dextrins, hemicelluloses	25.909	21.345	24.142	20.613
Total carbohydrates	30.708	25.735	28.781	24.958
Total nitrogen	1.230	0.828	1.077	0.678

*All percentages calculated on a dry weight basis except percentage of dry matter. All carbohydrates given in terms of glucose.

The various carbohydrate compounds and total nitrogen in these materials were determined, according to methods used by Leukel. The averaged results of these determinations on the crowns and roots of Napier grass from the sewage-irrigated and non-irrigated plats for the years 1926–29 are given on the percentage basis in Table 4 and on a quantity basis in Table 5.

In percentage of dry matter, the roots of the plants were considerably higher than the crowns. There was little variation in the percentage of dry matter in the roots and crowns of plants from the sewage-irrigated and non-irrigated plats for the period of 1926 to

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[3] LEUKEL, W. A. Utilization and deposition of reserve foods in alfalfa plants. Jour. Amer. Soc. Agron., 19: 596–623. 1927.

TABLE 5.—*Average weight in grams of dry matter, sugars, higher carbohydrates, and total nitrogen in crowns of sewage-irrigated and non-irrigated Napier grass dug previous to the production of spring top growth from 10 feet of row or an area of 60 square feet for years 1926 to 1929, inclusive.**

Compound	Crowns Irrigated with sewage effluent	 Not irrigated
Dry matter	2,064.747	621.460
Reducing sugars	72.535	21.453
Total sugar	99.335	28.830
Starches, dextrins, hemicellulose	534.955	150.033
Total carbohydrate	634.043	178.862
Total nitrogen	25.396	6.693

*All carbohydrates given in terms of glucose. All compounds calculated on a dry weight basis except dry matter.

1929 inclusive. On a percentage basis, the various carbohydrate compounds in the roots and crowns of the plants from the irrigated and non-irrigated plats show slight variations from one year to another, being slightly higher in the roots and crowns of the irrigated plats in most instances In percentage of carbohydrates, the crowns of the plants from the irrigated plats were higher during this period than those from the non-irrigated In the roots of the plants from the differently treated plats less difference was shown in percentage of total carbohydrates during this period. In percentage of total nitrogen, the roots and crowns of the Napier grass plants from the effluent-irrigated plats were consistently higher, except for those dug in 1929, in which case the roots of the plants from the non-irrigated plats were slightly higher.

The average percentage of total carbohydrates in the crowns and roots of the plants for this period was slightly higher in these plant parts from the irrigated plats The average percentage of nitrogen for the same period showed a more significant difference in favor of the crowns and roots of the plants from the effluent-irrigated plats.

The quantities of dry matter, various carbohydrate compounds, total carbohydrates, and total nitrogen in the crowns of the plants from the sewage-irrigated plats were approximately 3.5 times that of similar materials in the crowns of plants from non-irrigated plats (Table 5).

The ratio between the Napier grass silage yields of the non-irrigated and irrigated plats in 1922 at the end of the first year's irrigation was 1 : 1.8 which ratio widened to 1 : 2.0 in 1923, 1 : 2.8 in 1924, and 1 : 2.7 in 1925. After irrigation was discontinued in the fall of 1925, the average ratio of the silage yields between the non-irrigated and irrigated plats was 1 : 2.8 for 1926 and 1 : 3.8 for 1927, or an average of 1 : 3.3 for the two-year period (Table 6).

As given in Table 7, the ratios of the quantities of dry matter, total nitrogen, each of the various carbohydrate compounds, and total carbohydrates in the crowns of plants from non-irrigated and irrigated plats are approximately constant.

TABLE 6.—*Ratio of silage yield from non-irrigated plats to that from sewage irrigated plats.*

During Irrigation

Year	1922	1923	1924	1925
Ratio	1: 1.791	1: 1.963	1: 2.808	1: 2.725

After Irrigation was Discontinued

Year	1926	1927	Average
Ratio	1: 2.810	1: 3.807	1: 3.308

The average ratio between the quantities of dry matter, various carbohydrate compounds, total carbohydrates, and total nitrogen of the Napier grass crowns from non-irrigated and effluent-irrigated plats is 1: 3.5 for the four years during which they were analyzed.

TABLE 7.—*Ratios between the quantities of various plant compounds in crowns of Napier grass from non-irrigated and sewage-irrigated plats.*

Compounds					
Dry matter	Reducing sugars	Total sugars	Starches, dextrin, and hemicelluloses	Total carbohydrates	Total nitrogen
1: 3.322	1· 3.381	1: 3.446	1: 3.559	1: 3.545	1: 3.694

This ratio is very similar to that obtained between the yields of Napier grass silage from the non-irrigated and the irrigated plats after discontinuing sewage irrigation.

DISCUSSION

It is apparent that the continued large yields of Napier grass silage from the irrigated plats after the discontinuation of the irrigation with sewage effluent cannot be explained alone on the basis of a greatly increased soil fertility of the irrigated plats nor to water alone as shown by the yields of the city water irrigated plat. Again, the gradual widening ratios between silage yields from the non-irrigated and irrigated plats indicate a more effective utilization of various plant nutrients, especially nitrogen, furnished by the sewage effluent during the period of irrigation (1922 to 1925 inclusive). This more effective utilization of plant nutrients resulted in the production of a larger plant system. This larger plant system with its increased leaf area, in turn, was capable of elaborating larger quantities of organic foods. This condition is reflected in the increased growth of the lower storage parts of the plants and the large quantities of organic foods stored therein.

Analyses show that there are only slight increases in percentages of these organic compounds in the crowns of plants irrigated with sewage over those not irrigated. However, the quantities of carbohydrate and nitrogenous reserves stored in the crowns of the plants from the irrigated plats were 3.5 times as great as such food reserves in the crowns of plants from the non-irrigated plats. Likewise, the silage yields from the sewage-irrigated and non-irrigated plats are in direct proportion to the quantities of stored organic food reserves, being 3.3 times as high from the irrigated plats as from the non-irrigated plats. As already established by Leukel,[4] the quantity of early vegetative top growth produced is dependent upon the quantity of organic foods previously deposited in the storage parts of the plants. The subsequent growth of the plant and the storage of organic food reserves in the crowns depend upon a continued elaboration of carbohydrate and nitrogenous materials which must necessarily be attended with an absorption of nitrogen from the soil. The analyses of the crowns subsequent to the discontinuance of the irrigation indicate that this absorption of nitrogen in the irrigated plats has been more effective despite the very slight increases of nitrogen due to the irrigation. Thus, the establishment of a larger plant system on the sewage-irrigated plats brought about by the increased nitrogen supplied by the effluent necessarily accounts for the more effective utilization of soil nitrogen and the elaboration of organic foods for increased silage production

Judging from the above results, it is reasonable to assume that some perennial forage crops may be effectively established by the use of other nitrogenous fertilizers applied under favorable moisture conditions.

SUMMARY

A study was made of the possible utilization of sewage from septic tanks for the irrigation of forage crops. Plats of Napier grass and Japanese cane were established and irrigated with sewage effluent for four years.

Yields of silage from these plats as compared with silage yields from non-irrigated plats and plats irrigated with city water were taken during the period of irrigation, 1922 to 1925, inclusive, and thereafter (1926 28). Samples of soil for analyses were collected in 1925 immediately after the discontinuance of irrigation. Samples of crowns and roots of Napier grass were taken for analysis previous to production of early spring top growth for the years 1926 to 1929 inclusive.

During the period of irrigation, the silage yields of Japanese cane and Napier grass from the sewage-irrigated plats were higher than

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[4] *Loc. cit.*

yields obtained from the non-irrigated plats and from the plat irrigated with city water. The ratio of the yields from the non-irrigated to the sewage-irrigated plats widened during the period of irrigation.

The yields of Napier grass silage from the sewage-irrigated plats subsequent to the discontinuance of irrigation continued to be about 3.3 times greater than the yields from the non-irrigated plats.

Analyses of typical sewage effluent showed the presence of considerable quantities of nitrogen compounds. Analyses of the soil after the discontinuance of irrigation showed only slight increases in nitrogen content.

Analyses of the crowns and roots of Napier grass after irrigation was discontinued showed only slight increases in organic foods on a percentage basis. On a quantity basis, the amount of organic foods stored in the crowns of Napier grass from the sewage-irrigated plats were 3 5 times that in the crowns of similar plants from non-irrigated plats.

It appears that the early fertilization of the forage crop with nitrogen (and perhaps the added water) established a larger plant system which remained more effective for the better utilization of soil nutrients and the elaboration of organic plant foods for increased silage production

THE EFFECT OF BARNYARD MANURE ON A CALCAREOUS SOIL[1]

D. W. PITTMAN[2]

In a former article (1)[3] a series of experiments was reported in which an attempt was made to find by analytical methods something of an explanation of the necessity for barnyard manure in raising sugar beets on the highly calcareous and apparently rich soil of the Greenville Experiment Farm near Logan, Utah. Selecting certain typical manured and unmanured sugar beet plats the soil of each was analyzed for total nitrogen, nitrate nitrogen at different seasons, and organic carbon. In addition, the soils were tested for nitrification and for apparent specific gravity. By determining the coefficient of correlation between the yield of sugar beets on these plats and the various soil properties studied, it was seen that there was the most significant correlation between the yield of sugar beets and the nitric nitrogen in the soil in June; hence, it was concluded that "on this soil farm manure is of value to sugar beets not so much for its organic matter or for its physical or bacteriological effect on the soil as for the nitrogen it contains."

At that time the colorimetric coeruleo-molybdate method for determining water-soluble phosphorus in a soil as developed by Atkins (2), and used later by Parker and Fudge (3), was not so widely known, and considering the high content of total phosphorus of the soil (0.41% P_2O_5), it was not considered worthwhile to employ the more laborious methods of determining available phosphorus in the soil to ascertain whether or not this might be an important point in explaining the markedly greater yield of the sugar beets with the application of manure.

In 1929, in connection with some other work, it was found desirable to determine the soluble phosphorus in these plats. The results seem to be of sufficient interest to justify publication in a preliminary way since they modify the previous conclusion. The method used in the determination of soluble phosphate was essentially that of Atkins (2) and of Parker and Fudge (3), except that the extraction was carried out with water containing 0.5% of sodium alum as a flocculating agent which gave a clear extract without the necessity of filtering. The details of the method are as follows.

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[1] Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director December 6, 1929. Received for publication December 16, 1929.

[2] Associate Agronomist.

[3] Reference by number is to "Literature Cited," p. 552.

DETERMINATION OF SOLUBLE PHOSPHORUS IN SOIL (2, 3)

SOLUTIONS NEEDED

"A," Mix 100 cc of 10% $(NH_4)_2\ MoO_4$ solution with 300 cc of 50% (by volume) solution of H_2SO_4. Keep in dark.

"B," To 0.5 gram powdered tin add 5 drops of 4% solution of $CuSO_4$ and 10 cc concentrated HCl. Warm to hasten solution. Dilute to 50 cc. Make fresh each day.

STANDARD PO_4 SOLUTION

Dissolve 0.1433 gram KH_2PO_4 in distilled water in 1,000-cc volumetric flask. Add 0.5 cc toluene and dilute to mark. This contains 100 p.p.m. PO_4. Take 10 cc of this and dilute to 1,000 cc. This contains 1 p.p.m. PO_4. For standard color dilute 15 cc of this latter solution to 100 cc. Add 2 cc of "A" and 6 drops of "B" and make to 150 cc. (Make this latter fresh each day.) In a 100-cc colorimeter each 1 cc of this standard equals 2 parts per 100 million PO_4, using 50 cc 1:5 soil extract.

PROCEDURE

Place 42 grams of air-dry soil in a pint Mason jar. Add 200 cc water. Stir vigorously with a spatula. To clarify add exactly 1 gram of sodium alum $(Na_2SO_4.Al_2(SO_4)_3.24H_2O)$. Again stir vigorously with a spatula. Cover and let stand over night. With a pipette remove 50 cc of the clear extract and place in a beaker. Add 1 cc of reagent "A" and 6 drops of reagent "B" to develop color. Allow 5 minutes for color to develop and compare with standard in colorimeter.

TABLE 1.—*Soil analyses and crop yield on plats receiving different quantities of manure.*

Plat No.	Tons manure applied each year, average (a)	Tons manure applied since 1910 (t)	Nitric nitrogen in p.p.m. in May (n)	Soluble PO_4 in p.p. 100 m. in May (p)	Total organic matter % (o)	Yield of sugar beets in tons per acre (y)
3G	0.0	0	7	10	3.0	3.53
7G	10/4 = 2.5	5	7	20	2.1	13.95
21G	20/7 = 2.9	60	23	50	3.0	11.62
22G	20/7 = 2.9	50	14	56	3.3	6.67
28G	40.0	800	18	670	4.1	21.69
29G	15.0	300	20	550	2.8	17.91
30G	5.0	100	11	230	2.2	15.80
34G	0.0	0	9	50	2.5	3.02
35G	0.0	0	5	30	2.2	3.68
36G	0.0	0	8	34	2.4	2.29
37G	10/2 = 5.0	10	14	100	2.7	14.64
51G	0.0	0	6	30	2.2	4.05
52G	0.0	0	7	46	2.4	4.55
82G	30/10 = 3.0	30	8	114	2.5	9.29
90G	30/10 = 3.0	20	11	102	2.5	11.09
92G	30/10 = 3.0	30	7	100	2.6	10.47
100G	30/10 = 3.0	20	9	110	2.8	12.20

Run a blank determination, using water from the same source and 1 gram of alum (which usually contains some phosphorus) but no soil. Subtract the blank from the other readings. It is essential that the extract be perfectly clear as even a slight cloudiness due to clay in suspension will cause an abnormally high test.

The nitric nitrogen was determined from the same extract as the phosphate by the customary phenoldisulfonic-acid, colorimetric method and the organic matter was determined later by the rapid approximate method of Schollenberger (4). The soil analyses and crop yields are given in Table 1.

From these figures coefficients of correlation may be derived as shown in Table 2, using the standard formula

$$r_{(xy)} = \frac{\Sigma\,(xy)/n - \bar{x}\bar{y}}{\sqrt{\Sigma x^2/n - [\Sigma(x)/n]^2}\ \sqrt{\Sigma\, y^2/n - [\Sigma\,(y)/n]^2}}$$

as given by Hayes and Garber (5).

TABLE 2.—*Correlations between crop yield and soil analyses on plats receiving different quantities of manure.*

1 $r_{(yp)} = +0.77 \pm .07$ = correlation of yield to soluble phosphorus in the soil
2 $r_{(yn)} = +0.74 \pm .07$ = correlation of yield to nitric nitrogen in the soil
3 $r_{(ya)} = +0.74 \pm .07$ = correlation of yield to manure added to soil each year
4 $r_{(yt)} = +0.69 \pm .09$ = correlation of yield to total manure added to soil
5 $r_{(yo)} = +0.54 \pm .12$ = correlation of yield to organic matter in the soil
6 $r_{(pt)} = +0.92 \pm .03$ = correlation of soluble phosphorus in soil to total manure added
7 $r_{(pa)} = +0.92 \pm .03$ = correlation of soluble phosphorus in soil to manure added each year
8 $r_{(pn)} = +0.70 \pm .08$ = correlation of soluble phosphorus in soil to nitric nitrogen
9 $r_{(po)} = +0.67 \pm .09$ = correlation of soluble phosphorus in soil to organic matter
10 $r_{(no)} = +0.65 \pm .09$ = correlation of nitric nitrogen to organic matter
11 $r_{(nt)} = +0.65 \pm .09$ = correlation of nitric nitrogen to total manure added
12 $r_{(na)} = +0.65 \pm .09$ = correlation of nitric nitrogen to manure added each year
13 $r_{(ot)} = +0.85 \pm .05$ = correlation of organic matter to total manure added
14 $r_{(oa)} = +0.84 \pm .05$ = correlation of organic matter to manure added each year
15 $R_{(y.pno)} + 0.82 \pm .05$ = correlation of yield to combined effect of soluble phosphate, nitric nitrogen, and organic matter

From these correlations it seems that the amount of available phosphorus in this soil is very largely influenced by the amount of manure applied and that the low yield of sugar beets on the unmanured soil is due as much to the lack of soluble phosphorus in the early growing season as to the lack of nitric nitrogen. As in the previous results there is a smaller correlation between yield and organic content of soil than between yield and nitric nitrogen. Since this soil is relatively rich in total phosphorus (0.41% P_2O_5), it is possible that an explanation of its unavailability might be found in the high lime content of the soil which shows about 42% calcium and magnesium carbonate. Later in the season the soluble phosphorus of nearly all of these plats was reduced to an amount too small to be shown by this test. The high multiple correlation $R_{(y.pno)}$shows that the combined effect of the three factors—soluble phosphate, nitric nitrogen, and organic matter—is quite important in determining the increased yield of the manured plats.

From all of this it would seem that on this highly calcareous soil farm manure is essential to sugar beets largely because of its making the phosphorus available and increasing the content of nitric nitrogen in the soil.

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THE ORIGIN, NATURE, AND ISOLATION OF THE INORGANIC BASE EXCHANGE COMPOUND OF SOILS[1]

EMIL TRUOG AND J. A. CHUCKA[2]

In recent publications, Kerr (2, 3)[3] has reported evidence, secured while working in the senior writer's laboratory on the problem of soil acidity and base exchange, to the effect that the base exchange property of mineral soils and bentonite is due to an identical compound. He next proceeded to identify this exchange compound of soils and bentonite, but unfortunately had to give up the work before completion due to the necessity of returning to his native country, Australia.

At this stage the writers proceeded to investigate the origin of the base exchange compound of soils and bentonite. For an investigation of this kind a quick test for small amounts of the material in question is extremely useful, and fortunately a very satisfactory test for this purpose was easily devised.

SENSITIVE TEST FOR BASE EXCHANGE MATERIAL

The use of a base which, when taken up chemically by the exchange material, would give the material a distinctive color suggested itself. Base exchange material was treated with a copper salt, washed, and then treated with a little ammonia This gave a distinctive blue color to the material, but not of the intensity desired. Basic dyes were next tried and of those investigated fuchsine proved the most satisfactory. The procedure of the test as finally worked out is as follows.

Treat a pinch of the material to be tested with a little 0.5% water solution of fuchsine for a few minutes. Filter, preferably on a small Buechner funnel, wash with water and finally with alcohol until the filtrate comes through absolutely colorless This washing removes all of the dye held physically by colloidal silica and other non-exchange material. If base exchange material is present, it will be highly colored by the dye and may be viewed to advantage with the microscope. With scanty amounts of material the filter paper or shreds of it holding the material may be placed directly under the microscope.

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[1] Paper read as part of the symposium on "Application of Base Exchange Methods" at the meeting of the Society held in Washington, D. C., November 22, 1928. Published with the permission of the director of the Wisconsin Agricultural Experiment Station.

[2] Professor of Soils and Assistant in Soils, respectively, Department of Soils, University of Wisconsin, Madison, Wisconsin.

[3] Reference by number is to "Literature Cited," p. 557.

The dye may be easily displaced by treatment with a salt like KCl. The fact that the dye held by the exchange compound cannot be removed by washing with water or alcohol but can by washing with a salt solution indicates that it is held chemically.

With this test it is possible to detect minute amounts of base exchange material. The base exchange material of soils is shown to exist largely as colloidal material intimately distributed and to a considerable extent sticking to the crystalline mineral particles.

ORIGIN OF BASE EXCHANGE COMPOUND

The fact that the inorganic base exchange compound is of a colloidal nature and is universally found in soils suggested that it is of secondary origin and arises from parent material that is widely and abundantly distributed. Tests of fresh powdered granite gave negative results as regards its presence. Finely powdered samples of granite and the common soil-forming minerals were leached with carbonated water, the common weathering agent, but in all cases this failed to produce the base exchange compound.

A sample of decaying granite was next examined and the fuchsine test revealed the presence of the exchange compound apparently sticking largely to the surfaces of feldspar crystals. Feldspars contribute about 60% to the make-up of igneous rocks, and this appeared like a good lead as to the parent material. It is also known that certain alkali soils formed in the arid region are unusually high in base exchange material. Furthermore, bentonite deposits occur most abundantly in regious of low rainfall, and analyses of the gross bentonite material which probably has retained practically all of the alumina and silica of the parent minerals reveal, in most cases, an alumina-silica ratio approximating that of the alkali feldspars. These facts suggested that the base exchange material might be formed from feldspars under alkaline conditions of weathering.

Acting under this suggestion, small samples of the different feldspars, finely powdered, were placed in test tubes and covered with about 10 cc of water. The test tubes were shaken occasionally and the pH of the solutions determined at intervals. Hydrolysis took place quite rapidly and at the end of a week came practically to equilibrium at a reaction of about pH 8.4. There were slight variations in reaction with the different feldspars. It was found that a 1% solution of $NaHCO_3$ has a pH of about 8.3.

Accordingly, a sample of finely ground albite feldspar was next weathered by leaching with a 1% solution of $NaHCO_3$. After six days of leaching the weathered material was tested with fuchsine and found to contain appreciable amounts of the base exchange material. The sample was weathered for three weeks more and then subjected to a test of the Ca-Mg equilibrium constant. Although the amount of material at hand was inadequate for a rigid test, the value obtained for the constant K according to Kerr's method was found to be 1.14. This value is so near that obtained with soils and bentonite that there seems little doubt but that the compound in question had been prepared artificially.

Using the results of this experiment as a basis, the following theory regarding the origin of bentonite deposits and the base exchange material of soils is proposed.

Assuming the general belief (4, 5) to be true that the parent material of bentonite is volcanic dust, it is suggested that volcanic dust consisting largely of feldspars was either deposited in water or else submerged after deposition. Due to the porosity and fineness of the material, hydrolysis took place rapidly and the water soon came to a pH of approximately 8.4. At this pH the feldspars were unstable and broke down into silica and the base exchange compound, which is the essential constituent of bentonite

Soils are subjected to both acid and alkaline weathering. Between rains and periods of leaching, the films of water around the particles of feldspars come to a pH of 8.4. As a result, the feldspar gradually gives rise to base exchange material.

ISOLATION OF BASE EXCHANGE COMPOUND FROM BENTONITE

A sample of powdered bentonite which dispersed readily was suspended in a large proportion of water and agitated with a dispersing machine equipped as suggested by Bouyoucos (1), in order to secure more complete dispersion. The suspension thus secured was allowed to stand for several days in order to allow the unweathered minerals and coarse particles to settle, after which the supernatant suspension was siphoned off. In order to remove collodial silica and other extraneous material, the suspension was treated alternately with 2% Na_2CO_3 solution and N/10 HCl. Tests had shown that these reagents in the concentrations indicated do not affect the base exchange compound seriously. Each treatment lasted for at least 24 hours and was carried out at a temperature of about 75° C. After the first addition of acid or alkali, the base exchange material coagulated sufficiently to allow the greater portion of the supernatant liquid to be siphoned off. The treatment of acid and alkali was continued until no more silica and iron were being dissolved. At this stage the base exchange material assumed very definite and distinctive properties and gave all the appearances of being quite pure. The material was next washed by decantation with N/10 HCl until the wash solution no longer gave tests for bases, after which it was washed on a large funnel with water to remove the excess of acid. At the point where the acid was practically all removed, the material deflocculated and ran through the filter paper.

Samples of the material prepared as indicated were analyzed and the results indicated that the ratio of Al_2O_3 to SiO_2 in the compound is probably as 1:4. The compound, as regards flocculation and deflocculation, when treated with various bases and electrolytes, deported itself in a manner exactly analogous to a mineral soil of high base exchange capacity. This fact may be taken as evidence that the compound isolated and the one in soils giving rise to base exchange and soil acidity are identical. The effort is being continued to perfect further the procedure of isolating and purifying the compound.

ISOLATION OF BASE EXCHANGE COMPOUND FROM SOILS

The fact that the base exchange compound from bentonite when free of bases and electrolytes will completely deflocculate and then run through a filter paper served as a clue as to how the compound might be isolated from a soil. Accordingly, a sample of Colby silt loam subsoil, practically free of organic matter, was leached with N/10 HCl to remove the exchangeable bases, after which it was leached with water. As soon as the excess of acid and electrolytes was removed, a small amount of base exchange material came through the filter paper and gave the filtrate a milky cloudiness. The amount of the material coming through became much less in the course of 12 to 24 hours. If the soil is now dried and again leached with water, further crops of the material can usually be secured. The suspension secured in this way was then treated alternately with 2% Na_2CO_3 solution and N/10 HCl in exactly the same way as the suspension secured from bentonite. The resulting purified material had the same appearance and apparently the same properties in general as the material separated from bentonite. Chemical analysis also indicated that the substances from the two sources are identical.

SUMMARY

Continuing the work of Kerr who indicated that the base exchange compounds in bentonite and mineral soils are identical, the writers attempted to determine the origin and nature of the compound.

In the course of this investigation a test for minute amounts of the base exchange compound was developed. In this test a pinch of soil or other material under question is treated with a 0.5% solution of the

basic dye, fuchsine, and then washed with water and finally alcohol to remove all of the dye held physically. If base exchange material is present, it will be highly colored by the dye and may be detected to advantage with a microscope. The presence and location of the base exchange compound in soils may be readily shown with this test.

Evidence is presented which indicates that the base exchange compound is formed from feldspars under alkaline weathering conditions. Powdered albite leached with a 1% solution of $NaHCO_3$, which has a pH of about 8.3, gave rise to the base exchange compound. Water in contact with powdered feldspars attains a pH of about 8.4 in the course of several days. At this pH feldspars are unstable and break down into the base exchange compound and silica.

To explain the origin of bentonite, it is suggested that volcanic dust consisting largely of feldspars was either deposited in water or else submerged after deposition. Due to the porosity and fineness of the material, hydrolysis took place rapidly and the water soon came to a pH of approximately 8.4. At this pH the feldspars were unstable and broke down into silica and the base exchange compound, which is the essential constituent of bentonite.

Soils are subjected to both acid and alkaline weathering Between rains and periods of leaching, the films of water around the particles of feldspars come to a pH of 8.4. As a result, the feldspar gradually gives rise to base exchange material.

The base exchange compound was separated from bentonite by sedimentation and purified by treatment with N/10 HCl and 2% Na_2CO_3 solution. The purified material on analysis gave a ratio of alumina to silica of approximately 1:4.

A compound of similar properties and alumina-silica ratio was separated from a soil by leaching the soil first with dilute acid to remove bases and then water to remove the acid and other electrolytes. In the absence of bases and electrolytes, the base exchange compound deflocculates and may then be slowly leached out with water.

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THE GROWTH OF CERTAIN CONIFERS AS INFLUENCED BY DIFFERENT FERTILIZER TREATMENTS[1]

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Forest tree nurseries, due to limited area and intensity of management, are compelled to use fertilizers in some form if the quality of stock is to be maintained. Tree seedlings in no way differ from field crops in their dependence on the soil for plant food. Coniferous species undoubtedly demand different elements, while a much greater difference might be expected between conifers and hardwoods. The rôle of fertilizers is to increase growth and quality, whether it is brought about by an ameliorating effect upon the soil or by directly supplying the essential plant nutrients in available form.

Following the lead of agronomists, foresters and nurserymen have experimented with various kinds of fertilizers and with varying results. Much of the information available is very general and some of it contradictory. Preference today is for green manures, such as oats, rye, cowpeas, buckwheat, etc., or composted woods litter and soil, with combinations of these and the occasional addition of commercial fertilizers. The addition of humus to most nursery soils proves beneficial and, when space allows, green manuring is undoubtedly an excellent practice. The use of commercial fertilizers alone in most forest tree nurseries has met with indifferent success. This may be due to several causes, the principal one being rapid loss of fertilizer by leaching, as in sandy soils or soils deficient in other elements than those applied.

REVIEW OF LITERATURE

Definite data on results of fertilizing coniferous seedbeds, such as weight and length of top and roots of seedlings; length, number, and size of rootlets; soil analysis, especially pH reaction; and amount and analysis of fertilizer used are available in only a few instances and then not complete.

Hansen (5),[3] in a study of the effect of five different chemical fertilizers on the growth of white and red pine seedlings, found that neither species showed a preference for any one element. His check plat, on which no fertilizer had been applied, was among the best. He concludes that coniferous seedlings remove very little plant food from the soil, and that even in the light sandy soils with which he worked sufficient plant food is present to produce good seedlings over an extended period.

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[3] Reference by number is to "Literature Cited," p. 567.

Clark (2), in a report on the chemical analysis of 400 white pine seedlings, concludes that coniferous seedlings removed large amounts of plant food from the soil each year. On the basis of 4 square feet of seedbed bearing the above number of seedlings, it was calculated that 41.6 pounds of potash, 31.8 pounds of phosphoric acid, and 94.6 pounds of nitrogen were removed per acre.

The need of fertilization in permanent nurseries was also shown by Toumey (9). When working with a sandy loam, he found that two successive crops of two-year white pine seedlings are as many as can be grown without applying fertilizers There was a marked falling off in size and quality after the second crop, which he believes is due particularly to the absence of humus

Bates (1), working with sandy soil at the Halsey Nursery, Nebraska, found that dried blood, bone meal, and phosphate had no appreciable affect on the growth of coniferous seedlings He concludes, however, that this may be due to the fertilizers being rapidly washed out, or, more likely, because they did not change the physical composition of the soil Physical composition seemed to have the greatest effect on seedling growth An analysis of this soil showed that the growth of seedlings was but little influenced by the small quantity of humus, but that growth was affected by the amount of moisture-retentive clay present Good growth occurred where the percentage of alumina was from 2 05 to 2.76, and poor growth where the percentage was from 0.76 to 1 01. Manure was used to increase the water-holding capacity. Manure followed by cowpeas as a soiling crop gave good results. At the end of the first season, seedlings grown in the manured beds were from 1 to 2 inches taller than the others, and this difference was maintained during the second year

Toumey (9) states that, "Fertilizers are most effective when applied in the form of fertilized soil or compost." The danger of applying excessive amounts is not likely to occur and the fertilizers are brought to the young trees in their most useful form.

Retan (7), reporting on the results of experiments at the Greenwood Nursery in Pennsylvania, states that superphosphate is the only fertilizer unquestionably beneficial. Sodium nitrate used as a top dressing was a total failure and caused considerable loss. In an experiment at the Mont Alto Nursery in Pennsylvania, where charcoal residue from old pits was used on beds that had failed to raise conifers, Retan grew well-developed conifers.

In Austria, experiments in the use of fertilizer on growing pine and spruce, especially phosphoric acid, have been carried out (3). Deglutinized bone meal and Thomas slag were used, both of which are slowly soluble and, therefore, would remain in the soil longer. Variable results were secured even when the amounts of fertilizer were increased. It seemed evident that conifers cannot make use of phosphoric acid unless it is readily soluble. Combinations of potash, ammonium sulfate, and superphosphate were used with variable results. Of six beds fertilized with superphosphate, only four showed superior results; and in two the effect was less than with bone meal. At one point however, after three years, the superphosphate plants were 19% taller than the unfertilized; but only 1% taller than the bone meal seedlings This seemed due to washing of the soil combined with the greater solubility of the superphosphate, which leached out more readily. At another station, with less rainfall and no washing, the results were more favorable for superphosphate, in two years they were 40% and 35% greater than the results with bone meal. It is thought that, in the first year, the vegetative effect of superphosphate on spruce seedlings is greater than that of bone meal. In the second year the effect of both fertilizers, in rainy localities, is very nearly alike In very humid regions the effect of superphosphate is less On dry soil superphosphate appears to be consistently superior to bone meal.

Schwappach (10) conducted a series of experiments using kainit, Thomas slag, Chili salt peter, and a crop of lupines. He concluded that in fertilizing seedlings, nitrogenous fertilizers alone have proved of value, and these only when their effect is protracted over several seasons. Such legumes as lupines, black locust, or white clover gave the best results. Lupines, in every case, produced the most vigorous plants. Inoculation of soil with nitrifying bacteria of lupine root tubercles produced marked results.

Fifteen years of experimenting at the Forest Experiment Station, Sigmaria, Germany (6), showed that P_2O_5 and K_2O gave slightly better results than P_2O_5 alone, the latter being 100 as compared to 70 for check plats, based on height of seedlings. Calcium carbonate and $(NH_4)_2SO_4$ were ineffective and in many cases gave lower results than the checks. Plowing under clover as a green manure crop in connection with chemical fertilizer treatments gave better results than plats with chemical fertilizers alone.

In a series of experiments with several fertilizers at the La Minellie Nursery in France (4), the best results were secured with lime at the rate of 22 pounds per 120 square yards. It was concluded that the beneficial effects of superphosphate were due to its lime, of which there was very little in the soil (0.65%). The effect of KCl was not clearly shown. Potassium nitrate and cow manure without lime had a negative effect.

Wahlenberg (11) was able to increase root development of western yellow pine seedlings by varying the depth of the application of fertilizers in the seedbed. His results show the possibility of stimulating root development locally, in certain parts of the root system, by means of layers of rich soil.

Sundling (8), in studying the effect of soil reaction on the early growth of certain coniferous seedlings, concluded that reaction value (pH) alone was not of primary importance; other soil factors, such as the availability of various elements, base exchange, moisture conditions, etc., being of equal importance. His data show, however, that there is a rather definite range for optimum growth in the soils used. The most healthy and largest seedlings of all species were usually produced between pH values of 4.0 and 6.0, with an optimum of 5.0. Norway spruce preferred a slightly less acid soil than did red, jack, or white pine, this preference being more pronounced in different soils.

EXPERIMENTAL DATA

The experiments here reported were designed to test the value of certain commercial fertilizers for coniferous seedbed use and to determine if a single element, or a combination of elements, aid materially in producing vigorous seedlings in the field.

Many previous investigations have shown that moisture, fertility, physical properties, aeration, and temperature influence root growth. In this experiment, fertility was the only variable factor. Seedlings were grown in nursery plats and out doors in boxes during the summers of 1928 and 1929 and in greenhouse pots during the winter of 1928-29. Seedlings were recovered from the pots and boxes by using a fine spray and washing the soil away from the roots. Seedlings with broken roots were discarded. The weights given in Tables 1 and 3 are based on oven-dried seedlings; the data in Table 2 represent seedlings left exposed for 3 weeks on indoor benches (air-dried). The data include weights and measurements of 4,937 seedlings taken from 52 nursery plats, 56 pots, and 22 boxes.

The fertilizers used were limestone ($CaCO_3$), 16% superphosphate (P_2O_5); KCl, 48% K_2O; $NaNO_3$, 15%N; $(NH_4)_2SO_4$, 20.5% N; dried blood, 8%N; also, white oak leaves and white pine needles, both finely ground. The amounts and combinations used appear in the various tables.

Averaged data for pots and plats varied somewhat within each series. This variance could not be treated statistically. It is felt, however, that because of the consistency of the data the figures are significant in showing the relative value of the various fertilizers used on the three soils.

SERIES I

Boxes 18 x 12 x 10 inches deep were painted on the inside with a water-proofing asphaltum paint and filled to within 1 inch of the top with screened sand taken from a pit 6 feet deep. Fertilizers were applied and worked into the top 1½ inches of sand. One hundred white pine seeds were planted in each box. The soil was kept moist by regular watering until germination began. The boxes then were placed on benches out of doors and left without further watering. An attempt was made to limit the number of seedlings in each box to 60, but uncontrolled losses occurred which reduced the number of seedlings per box to less than 60 in most cases. During the winter the boxes were placed in an unheated cellar and watered twice during the winter. The first of April the boxes were again moved outdoors and left until the last of September. At the time the seedlings were removed, soil samples were taken, and pH values determined electrometrically. The results are given in Table 1.

TABLE 1.—*Average weight of two-year-old white pine seedlings from sand boxes treated with various fertilizers.*

Basis No. of boxes	Treatment*	Rate in pounds per acre	Average weight of seedling in mgm			Soil pH values
			Tops	Roots	Total	
2	Ca, 2,000; Na, 100	2,100	66.4	64.1	130.5	6.41—6.88
2	Ca, 2,000, Na, 100; K, 100; P, 100	2,600	70.1	57.7	127.8	6.18
1	Ca, 2,000; Na, 100; K, 100	2,200	58.2	53.6	111.8	6.63
1	Ca, 2,000	4,000	57.7	50.9	108.6	6.68
2	K, 100	100	57.9	48.4	106.3	5.65—5.92
2	P, 400	400	55.6	48.0	103.6	5.48—5.65
2	Na, 100; K, 100; P, 400	600	51.2	50.3	101.5	6.35—7.00
2	K, 100; Na, 100	200	48.8	50.6	99.4	6.01—5.68
2	P, 400; Na, 100	500	50.3	48.9	99.2	5.38—5.78
2	P, 400; K, 100	500	47.5	48.7	96.2	5.48—6.28
2	Na, 100	100	48.1	45.9	94.0	5.86—5.92
2	None		45.3	44.7	90.0	5.58—5.70

*Ca = Limestone; Na = $NaNO_3$; K = KCl (K_2O); P = Superphosphate.

No marked variance in soil pH values were noted, but it is interesting to note that the largest roots developed where the reaction values were from 6.01 to 7.00. The heaviest seedlings were found in the boxes treated with lime, alone or in combination. In all cases fertilizers proved beneficial.

SERIES II

In this series white and pitch pine seedlings were grown for two years in nursery beds. Each bed was 4 x 3 feet and framed in by boards 8 inches wide painted with an asphaltum water-proofing paint. The soil was a Hagerstown silt loam which had been used for lining out stock and to which no fertilizer had been applied for over 15 years.

Prior to seeding, the soil was well worked, heavily watered, and allowed to settle. The various fertilizers were worked into the top 1½ inches of soil. The beds then were divided and seeded with equal amounts of white and pitch pine seed They were watered twice prior to germination, screened against birds and rodents, and mulched with oak leaves during the winter. During the two growing seasons, the beds were regularly weeded and thinned Damping-off occurred on all plats to which lime was applied. Because of their irregular stocking, these plats are not considered

From each plat two bundles of 25 seedlings each were taken and all data are based on these samples. Table 2 gives the average weight of these samples. Dried blood at the rate of 200 pounds per acre pro-

TABLE 2.—*Average weight of white and pitch pine seedlings taken from nursery beds treated with different fertilizers on Hagerstown silt loam.*

Basis No. of plats	Treatment*	Rate in pounds per acre	Average weight of seedlings in mgm Pitch pine	White pine
2	Na	100	368.30	201.20
2	Na	150	284.55	192.05
2	Na	200	292.50	174.35
2	P	400	235.73	236.10
2	P	600	310.80	209.90
2	P	800	373.75	199.10
2	K	100	241.20	190.50
2	K	150	304.10	171.35
2	K	200	347.66	172.60
2	Na, P400, Na 100	500	320.40	239.55
2	Na, P600, Na150	750	373.80	205.00
2	Na, P800, Na200	1,000	361.07	205.40
2	K, Na	200	416.60	186.50
2	K, Na	300	400.00	221.05
2	K, Na	400	391.30	196.95
2	P, 400, K100	500	311.00	211.60
2	P, 600, K150	750	321.45	189.35
2	P800, K200	1,000	486.00	185.55
2	Na,100, K100, P400	600	484.20	219.90
2	Na,150, K150, P600	900	480.65	194.35
2	Na,200, K200, P800	1,200	379.70	195.20
1	D. B.	200	399.10	258.40
1	D. B.	300	462.60	176.40
1	D. B.	400	545.30	226.10
1	N(ams)	100	368.90	210.80
1	N(ams)	200	435.60	216.50
1	N(ams)	400	506.20	218.90
4	Check		396.95	194.30

*Na = Nitrate of soda; P = Superphosphate; K = K_2O (muriate of potash); D.B. = Dried blood; and N(ams) = Ammonium sulfate.

duced the largest white pine; at the rate of 400 pounds, the largest pitch pine. The pitch pine responded to increasing amounts of dried blood, while the white pine showed an irregular response. Both of the pines responded to increased amounts of ammonium sulfate. With sodium nitrate, their average weights decreased with applications in amounts of over 100 pounds per acre. Probably this is due to the sodium nitrate going into solution rapidly and becoming toxic to the seedlings. Pitch pine showed a marked response to increased amounts of potash and phosphorous, both when applied singly and together. White pine, however, showed a falling off in average weight with increasing amounts of P and K.

In nearly all cases the beds showed fairly consistent results. Arranged in order of average weights, the white pine check plats ranked nineteenth and the pitch pine eleventh.

SERIES III

One- and 2-gallon butter crocks were used, holding approximately 7 and 9 kilograms of soil, respectively The soil was a DeKalb silt loam taken from a woodlot representing the first 6 inches of mineral soil after the litter and humus had been raked away. The soil was screened through a one-quarter inch meshed screen and well mixed before being placed in the pots. The moisture content was determined by taking repeated samples and the soil was brought up to optimum moisture content (50% water-holding capacity which was 52%) before the seeds were planted.

The fertilizers were worked into the top 1½ inches of soil. Top watering was practiced during the germinating period. Following germination, both top and bottom watering was practiced bringing the soil up to optimum moisture. Twenty seeds of both white pine and Norway spruce were planted in each pot. Damping-off and thinning reduced the number of seedlings per pot to about 20. Temperature and humidity fluctuated considerably during the five months that the seedlings were growing.

Tables 3 and 4 give averaged data on measurements and weights of the pot-grown seedlings. Table 3 shows that the heaviest white pine seedlings were found in the pots treated with dried blood at the rate of 200 pounds per acre. The seedling roots from these pots were the heaviest in the series; but, as noted in Table 2, they were not the longest nor best developed. Sodium nitrate and superphosphate, alone and in combination, produced the next best seedlings. Norway spruce showed the greatest response to phosphorous, followed by L,N,P,K, and lime alone. Ammonium sulfate produced heavier seedlings than either dried blood or sodium nitrate. The poor top development in the P-K plat is unaccounted for. With the exception of these pots, a fertilizer response was evidenced in all pots as compared with the checks.

TABLE 3.—*Average weight of seedlings grown in DeKalb silt loam treated with various fertilizers, and in pots under greenhouse conditions.*

Basis No. of pots	Treatment*	Rate in pounds per acre	Basis number of seedlings	Average weight of seedlings in mgm		
				Top	Roots	Total
		White Pine				
4	D. B.	200	38	20.16	30.09	50.25
4	Na	100	29	20.26	25.55	45.81
6	P	400	77	16.89	28.55	45.44
4	P400, Na100	500	26	17.66	24.41	42.07
4	K100, Na100	200	31	16.92	23.58	40.50
4	Ca	2,000	52	16.98	23.45	40.43
2	Ca2000, P400, Na100, K100	2,600	22	22.73	17.50	40.23
	P400, K100	500	35	22.82	17.00	39.82
4	PN	2,000	25	18.60	20.80	39.40
2	P400, K100, Na100	600	20	13.56	25.19	38.75
4	K	100	48	16.00	21.25	38.25
6	N(ams)	100	49	20.10	17.35	37.45
2	OL	2,000	31	13.29	22.71	36.00
2	N(ams)	200	18	21.38	13.61	34.99
4	Check		55	18.07	13.07	31.14
		Norway Spruce				
6	P	400	59	14.23	27.36	41.59
2	Ca2000, P400, Na100, K100	2,600	20	23.00	11.75	34.75
4	Ca	2,000	26	18.46	15.69	34.15
4	P400, K100, Na100	600	27	17.69	16.11	33.80
2	N(ams)	200	16	19.07	10.94	30.01
4	N(ams)	100	52	18.27	10.58	28.85
2	PN	2,000	23	15.65	12.39	28.04
4	K100, Na100	200	19	11.84	14.74	26.58
2	OL	2,000	35	16.00	10.29	26.29
4	P400, Na100	500	45	11.75	14.47	26.22
4	Na100	100	47	10.74	15.21	25.95
4	D. B.	200	40	15.25	10.50	25.75
6	K	100	69	14.29	11.23	25.52
4	Check		45	14.44	7.44	21.88
4	P400, K100	500	43	11.51	10.09	21.60

*D.B. = Dried blood; Na = Nitrate of soda; P = Superphosphate; K = K_2O (muriate of potash); Ca = Limestone; PN = Pine needles; OL = Oak leaves: and N(ams) = Ammonium sulfate.

Growth of the white pine seedlings in this series can be slightly correlated with their weights, with the exception of the dried blood pots. This exception may be accounted for by the too succulent growth produced. The longest roots were in the sodium nitrate and sodium nitrate-superphosphate pots. Dried blood, phosphorous, and potash produced the longest hypocotyle. The N,P, and P-N pots produced white pine seedlings with the greatest number of laterals.

Norway spruce developed the greatest number of laterals under combination treatments of P,K, and N, followed by these fertilizers

TABLE 4.—*Average measurements of seedlings grown in DeKalb silt loam treated with different fertilizers in pots under greenhouse conditions.*

Basis No. of pots	Treatment*	Pounds per acre	Basis No. of seedlings	Average total length in cm of			Average length of seedlings in cm	Total number of laterals over						
				Top	Stem	Roots		½ cm	1 cm	3 cm	5 cm	8 cm	10 cm	15 cm
					White Pine									
4	Na	100	29	1.71	2.82	24.47	29.00	14.14	7.00	4.53	3.27	1.86	1.41	0.59
4	P400, Na100	500	26	1.73	2.86	22.86	27.44	11.00	8.19	4.00	2.65	1.50	0.71	0.01
4	Ca	2,000	52	1.91	2.77	22.51	27.79	10.14	7.98	4.54	2.88	1.48	0.83	0.03
4	K100, P400, Na100	600	20	1.84	2.59	22.35	26.78	9.25	7.00	2.95	1.70	1.20	0.85	0.04
4	P400, K100	500	35	1.89	2.80	21.99	26.68	9.37	6.89	3.43	2.20	1.37	0.83	0.03
4	K100, Na100	200	34	1.97	2.62	21.12	25.71	10.24	8.47	4.26	2.59	1.59	1.09	0.53
6	P	400	77	1.87	2.92	20.55	25.34	11.96	8.93	3.72	2.29	1.18	0.76	0.19
6	K	100	48	1.81	2.99	19.86	24.66	8.50	6.31	3.19	1.89	1.15	0.62	0.27
4	D. B.	200	38	1.87	3.08	19.21	24.16	9.44	7.24	3.47	1.87	0.93	0.55	0.21
4	Check	—	55	2.12	3.42	15.34	20.88	9.05	6.45	2.76	1.47	0.65	0.38	—
4	N(ams)	100	49	1.86	3.02	14.71	19.59	8.04	5.37	2.31	1.29	0.63	0.34	0.01
					Norway Spruce									
4	K100, Na100	200	20	1.67	2.59	15.05	19.31	9.05	5.70	2.20	1.10	0.60	0.03	—
4	P400, Na100, K100	600	37	1.59	2.62	14.76	18.98	8.43	5.03	1.68	0.87	0.27	0.01	—
4	P400, Na100	500	45	1.47	2.52	14.13	18.13	11.78	6.60	1.71	0.60	0.18	0.04	—
6	P	400	58	1.50	2.25	13.50	17.77	11.41	5.53	1.96	1.00	0.22	0.09	—
6	K	100	69	1.52	2.79	13.34	17.65	7.77	4.51	1.20	0.49	0.09	0.03	—
4	Na	100	47	1.52	2.11	14.01	17.64	9.64	4.98	1.40	0.43	0.11	0.04	—
4	P400, K100	500	44	1.57	2.59	13.38	17.55	8.16	4.93	1.00	0.36	0.01	—	—
4	D. B.	200	40	1.59	2.74	12.64	16.98	11.45	6.00	1.08	0.55	0.01	—	—
4	Ca	2,000	36	1.57	2.54	12.78	16.89	11.39	6.22	1.67	0.47	0.03	0.03	—
4	N(ams)	100	52	1.52	2.99	11.68	16.19	7.79	3.63	0.75	0.21	0.04	—	—
4	Check	—	45	1.42	3.28	10.99	16.70	6.29	3.58	0.62	0.18	—	—	—

*Na = Nitrate of soda; P = Superphosphate; Ca = Limestone; K = K_2O (muriate of potash); D.B. = Dried blood; and N(ams) = Ammonium sulfate.

individually in the order given. The greatest number of laterals found on the Norway spruce were in the P-N, P, dried blood, and lime pots. It is of interest to note that in case of both the white pine and Norway spruce seedlings the longest hypocotyls and the shortest roots were found in the check pots, excepting white pine in the ammonium sulfate pot. The pH values of the soil in these pots ranged from 5.2 to 5.8 and are not considered as having materially influenced growth.

SUMMARY

The data presented show that the three conifers used in these experiments were influenced in both their root and top development by the various fertilizers used, these responses varying with the soil type and the fertilizer.

In nearly all cases the seedlings grown on fertilized soil were larger, better developed, and heavier than those grown on the checks.

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BACTERIAL WILT OF ALFALFA[1]

Fred Reuel Jones[2]

Among the several aspects under which bacterial wilt of alfalfa might be discussed, two have been selected which are believed to be of chief interest among agronomists One is the relation of winter injury to bacterial wilt; the other is a discussion of methods whereby resistance to wilt may be sought and studied. The search for resistance and an examination of the character and limitations of any resistance that may be found are tasks in which agronomist and pathologist must participate. A consideration of the utility of methods is essential to effective participation. Inasmuch as mechanical injuries to the alfalfa plant resulting from winter freezing appear to be the most frequent condition making infection possible, a review of the precise manner in which these injuries develop is a useful background against which methods of artificial inoculation may be compared and developed. The great need for artificial methods in the study of resistance to this disease will become apparent later.

The natural course of infection in bacterial wilt has been described previously and may be reviewed very briefly here.[3] The bacteria causing wilt enter the plant through wounds. These wounds may be any exposure of the living active parenchymatous tissue of the plant to water in which the bacteria may be carried. The bacteria do not live and grow in dead tissue. The wounds to which natural infections have been traced thus far have always been in root or crown close to the soil level. The wounds may be very slight indeed and not of themselves damaging to the plant to any appreciable degree. From the point of first contact with living cells the bacteria grow between the larger younger cells chiefly in the rays until they pass through the cambium and enter vessels. When the bacteria have entered vessels, they are easily carried in water currents a long way up into the stems and down into the taproot where they cause a plugging not only of the vessels in which they have entered, but of nearby vessels. This process of plugging is not rapid, and while it is going on the plant if growing rapidly is adding new vessels which the bacteria must enter if the growth is to be checked sufficiently to cause symptoms of disease to appear. In the period of rapid root growth in early summer the plant frequently adds new vessels so rapidly that the disease is outgrown temporarily or permanently if the initial infection is slight. Thus, under natural conditions, plants infected in the spring may not show symptoms of disease during the entire following summer, but may die during the second summer.

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[1] Paper read as part of the symposium on "Alfalfa" at the meeting of the Society held in Chicago, Ill., Nov. 14, 1929. Abridged for publication.

[2] Senior Pathologist, Office Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

[3] Jones, Fred Reuel. Development of bacteria causing wilt in the alfalfa plant as influenced by growth and winter injury. Jour. Agr. Res., 31:545-569. 1928.

The manner in which winter freezing often opens wounds suitable for infection, and thus becomes the precursor of epidemics of wilt, has also been described previously and need not be reviewed here.[4] It may be stated, however, that in developing methods whereby plants may be tested for resistance an effort has been made to produce artificially wounds similar in character to those produced by winter freezing, and to surround the plant with growing conditions similar to those which obtain when the natural wounds are opened. The great need for developing a method whereby great numbers of plants may be wounded artificially in imitation of winter injury arises largely from the fact that experience has shown that in any selected locality several winters may pass in which no natural wounding takes place of sufficient intensity to provide easy access of the bacteria to large numbers of plants in the field. Thus field tests are of uncertain outcome.

Before discussing methods of testing alfalfa for resistance to wilt, the evidence pointing to the existence of resistance in alfalfa plants must be examined. Unfortunately, there are, so far as I am aware, no published observations which may be cited here. However, the first observers of the disease noted that in old fields scattered plants sometimes survived uninfected or with overgrown infection Later, in localities in Nebraska and Kansas where the disease had been destructive, certain old fields were found almost free from disease more or less surrounded with severely infested fields It has also been a matter of common knowledge among many agronomists in several state experiment stations that in several trial plantings of varieties of alfalfa conducted cooperatively with the U. S Dept. of Agriculture bacterial wilt has entered and has apparently destroyed more plants in some regional strains than in others. Occurrences of this kind suggest that some regional strains contain large numbers of resistant or immune plants, while perhaps all varieties contain some plants capable of resisting infection or of outgrowing the disease. This hypothesis confronts us at once with the problem of methods whereby the occurrence and the character of resistance in a variety or in individual plants may be adequately determined.

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[4] JONES. FRED REUEL. Winter injury of alfalfa. Jour. Agr. Res., 31:189–211. 1928.

It will not be profitable to consider here all of the methods of artificial wounding and inoculation that have been tried with little or no success to secure uniform and early infection of large numbers of plants before describing a method that has given much promise of success in the past year. Effort has been made in three directions; first, inoculation of plants artificially frozen; second, inoculation of plants through cut stems; and third, inoculation in artificial wounds.

Equipment has not been available for freezing plants on a large scale in the soil. When plants have been removed from the soil for freezing they usually grew very poorly after transplanting whether inoculated or not and no infection has resulted. The rather obvious difficulties with this method are so great that it has been discarded.

Inoculation of plants in the field through cut stems was made with considerable success several years ago by mowing plants thoroughly wet with a bacterial suspension. This method has proved successful only with plants several years of age. Thus far it has given very little infection with plants in their first summer, and has often failed with plants in their second summer. Infection resulting from such inoculations are more easily overgrown than infections from wounds in the root. Thus this method does not seem satisfactory for the present purpose.

The experiment whose outcome at present indicates most clearly a successful method for the determination of resistance to bacterial wilt in alfalfa plants in the space of a year involves the inoculation of wounds made in roots when transplanted from the greenhouse to the field in the spring. Seed of several varieties were sown in flats in the greenhouse in October, 1928. Seedlings were transplanted to deep flats where they grew slowly until April 17. At that date they were removed from the soil, washed, and the roots scraped with a knife. The knife edge was drawn twice down the taproot with sufficient pressure to remove the outer bark to approximately the depth that this bark is sloughed after winter injury. Care was taken not to cut through the cambium. The roots were then dipped in a bacterial suspension and planted in rows in the field. The plants grew very vigorously and when first cut on June 28 few showed evidence of disease. After the third cutting many showed evidence of disease and some died. At this time the difference in severity of disease between the several varieties was conspicuous. In the autumn it was impossible to distinguish in all cases by outward appearance those plants in which disease had not developed severely or in which it had become temporarily overgrown from those which were not infected.

In order to determine the extent to which plants were diseased before removal from the soil, on October 25 a large shoot was removed from each apparently healthy or doubtful plant and examined for the presence of the parasite. If the parasite was not found in the shoot, the plant was adjudged free from disease or with overgrown infection. The findings at this time are presented in Table 1.

TABLE 1.—*Visible result on October 25 of inoculation on April 17 of plants of alfalfa varieties with bacteria causing wilt.*

Variety	No. of plants inoculated	No. of plants dead	No. of plants with disease apparent	No. of plants with disease not apparent
Grimm	55	34	12	9
Kansas	53	33	10	10
Peruvian	100	58	8	34
Ladak	50	14	3	33
Turkestan (2)	57	13	9	35
Turkestan (7)	73	23	16	34
Hardistan	55	0	12	43

Finally, all plants in whose stems no bacteria were found were transplanted and the roots were sectioned to discover infections so deeply overgrown that bacteria had no access to the stems. The results of this examination are given in Table 2. The association of this frequency of disease escape with high ability to overgrow infection suggests strongly that a high degree of disease resistance is present in the Ladak, Hardistan, and Turkestan strains used here.

This trial is so small in extent that it can be given little significance by itself. However, a much larger trial conducted in a somewhat similar manner but not yet completed promises to give like results. The large trial conducted wholly in the field and thus avoiding the use of greenhouse space, but requiring two years for its completion, was started, as follows. Seed of the strains under test was sown early in the spring of 1929 Seedlings were considered large enough for inoculation and transplanting early in August Inoculation was made at time of transplanting as in the case of the plants grown in the greenhouse. The appearance of disease was not expected before the summer of 1930, but in fact before cold weather checked the development of the pathogenic bacteria a small percentage of Grimm, Kansas, and Peruvian plants died while only a single plant among the Turkestan transplants gave evidence of disease. Judging by such superficial evidence as could be gained in the autumn of 1929, most of the common strains will be rapidly reduced by disease early in the summer of 1930.

From the experimental work cited here, small though it is in amount, it appears that certain regional strains of alfalfa do contain considerable numbers of plants which are resistant to bacterial wilt under the conditions of the experiments. Whether such resistance would appear in similar experiments conducted in other locations and whether it will be maintained as plants grow older and under all field conditions, remains to be determined. Moreover, it is unsafe to assume at present that all strains of alfalfa grown in Kansas or of Grimm are as susceptible to wilt as the selections used in these experiments. The task of examining available seed sources for resistant strains is before us. It is possible that briefer and better methods of making comparative tests of varieties may be developed as soon as more precise knowledge of the character of resistance has been gained. Work in this direction is in progress.

TABLE 2.—*Percentage of plants killed, infected, and uninfected in the several varieties inoculated with bacteria causing wilt on April 17, 1929.*

Variety	Dead	Infected	Uninfected
Grimm	60	40	0
Kansas	60	38	2
Peruvian	58	41	1
Ladak	28	52	20
Turkestan (2)	23	56	21
Turkestan (7)	31	54	15
Hardistan	0	70	30

These results do, however, increase the hope that seed sources of more or less resistant alfalfa exist and may be discovered. If the resistance thus found ,in existing strains is not adequate for commercial needs, it may be increased by selection and breeding, and combined with preferred agronomic characters. The first step in rapid progress toward the achievement of this hope is the development of a method whereby comparisons can be made more swiftly than by the usual type of field trial, even though such field trial must be the final test by which resistance is measured.

NOTES

OAT VARIETIES HIGHLY RESISTANT TO CROWN RUST

A variety of oats, Victoria (C. I. No. 2401), showed unusual resistance to crown rust (*Puccinia coronata avenae*) in 1929. This variety was observed under field conditions at the Iowa (Ames) and Kansas (Manhattan) Agricultural Experiment Stations.[1] At both stations it was "highly resistant" to a severe epiphytotic of crown rust in 1929. One hundred and fifty-six cultures of crown rust were collected in the central, southern, and northwestern portions of the United States in 1929. Using a standard set of differential hosts for identification, the senior writer found that these 156 cultures included eight physiologic forms of crown rust. Victoria (C. I. No. 2401) was inoculated with each of these forms in the seedling and mature stages. In every case it showed an "apparently immune," "completely resistant," or "highly resistant" type of reaction.

A second and similar, if not identical strain, received under the name of "Avena Victoria" (C. I. No. 2764) has shown like resistance to the eight physiologic forms collected in 1929.

Another variety, *Avena strigosa* var. *glabrescens* (C. I. No. 2630), showed resistance under field conditions equal to that of Victoria strains and was resistant to all except one of the eight physiologic forms collected in 1929.

Victoria (C. I. No. 2401) was obtained from Enrique Klein's Plantation of Agricultural Plants, Station Plá, Province of Beunos Aires, Argentina. It was received on May 20, 1927, with a collection of wheats from Argentina consigned to the U. S. Dept. of Agriculture. Victoria (C. I. No. 2764) was obtained in April, 1929, by the Plant Pathology Section, Iowa Agricultural Experiment Station, from José M. Scasso, Regional Agronomist, Morón, Province of Buenos Aires, Argentina. *Avena strigosa* var. *glabrescens* (C. I. No. 2630) was received by the Office of Cereal Crops and Diseases in April, 1929, from Prof. H. Wenholz, Department of Agriculture, Sydney, New South Wales, Australia. It was accessioned under F. P. I. No. 78821.

The variety Victoria has some of the characteristics of both common and red oats. In its plant and certain kernel characters the variety resembles Burt, Fulghum, etc. The culms and lemmas show the reddish yellow of the varieties belonging to *Avena byzantina*. The florets, however, separate as they do in varieties of *A. sativa*. The awns are mostly twisted and geniculate. The variety may have resulted from a hybrid between these species.

If Victoria itself does not prove of agronomic worth, it should be very valuable in the development of hybrid varieties resistant to crown rust and adapted to the southern states, where this fungus frequently takes a heavy toll. *A. strigosa* var. *glabrescens*, because of its chromosome number (haploid 7), is of doubtful value for breeding purposes, unless for the development of hay varieties of *A. strigosa*.—H. C. MURPHY and T. R. STANTON, *Bureau of Plant Industry, U. S. Dept of Agriculture, Washington, D. C.*

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[1] **Cooperative investigations between the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa and Kansas Agricultural Experiment Stations.**

HARVESTING EXPERIMENTAL GRAIN PLATS WITH A COMBINE

The past 10 years have witnessed changes in the methods of producing wheat in the southern Great Plains, the importance and significance of which have probably never been equaled in a similar period of time. As a result of these changes, the conditions under which wheat is grown are very different from what they were, and consequently, many of the experiments laid out 20 years ago do not adequately fit current cultural methods and problems of production.

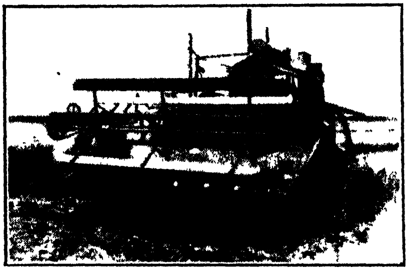

FIG. 1

The most important change worthy of note in connection with the purpose of this note is the extensive use of the combine for harvesting. Compared with the header method, the combine scatters the straw on the ground instead of leaving it in stacks, and compared with the binder method it leaves a high stubble as well as scatters the straw on the land. Most experimental plats are harvested with a binder, usually with a low stubble, although in some cases efforts have been made to leave a high stubble, thus approximating the header method of harvesting If the harvesting is done by either binder or header, the subsequent condition of the ground is not identical with that under modern farm conditions. Hence, the question naturally arises whether such experiments, especially those relating to the preparation of the ground, can be expected to give results which can strictly be applied to practical problems.

This situation has been the subject of considerable concern at the Fort Hays Branch of the Kansas Agricultural Experiment Station for a number of years, culminating recently in the construction of a small combine which has been successfully used in harvesting experimental plats (Figs. 1 and 2).

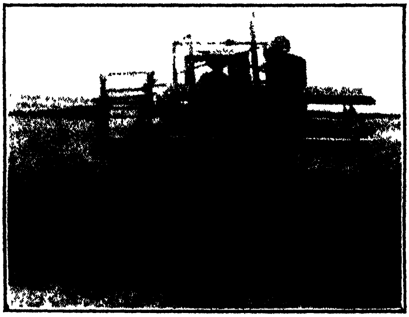

FIG. 2

The first attempt to handle the experimental plats at the Fort Hays Branch Experiment Station in accordance with modern methods of harvesting was in 1925 when the junior author removed the binder proper from an ordinary grain binder and attached boxes to receive the headed grain, the crop being cut with a high stubble. The grain was then threshed in the usual manner. The same method, with some improvements, was followed for the harvest of 1926.

In 1927, a gleaner combine, mounted on a Fordson tractor and propelled by the tractor motor, was employed to harvest the experimental plats. This combine was chosen because it is the only push type on the market, and consequently, the only kind that can make the necessary turns and be operated between plats without destroying the grain. Two men were required to operate the machine, one to run the tractor and one to take care of the grain By careful manipulation, it was found possible to harvest individual plats without injury to adjacent standing plats The harvest in that year was completed in two days, whereas about eight days would have been required for harvesting, shocking, and threshing by the usual methods, thus saving a great deal of time, labor, and money The early completion of the harvest also permitted early preparation of the soil for the next crop, thus agreeing with farm practice more nearly than had previously been possible

In 1928, a gleaner combine was purchased and mounted on a 2-ton (now known as a "fifteen") caterpillar tractor. A Ford motor was mounted on the gleaner for its operation so that a steady source of power to run the machinery of the gleaner would be available at all times. This proved to be an excellent harvester and, with a few minor improvements, was used again in 1929 In the latter season, a total of 266 one-tenth acre plats were harvested in four days, the average yield being 30 bushels per acre. The cost, not including depreciation, amounted to 19 cents per plat compared with 90 cents per plat had the binder been used. The combine was also used to harvest many of the plats on the cereal crops project, most of which were one-fortieth or one-fiftieth acre in size. It did excellent work here, although it is not adapted to harvesting different varieties the seed of which must be kept pure for future seeding The loss of grain by the combine method appeared to be less than by the binder method.

The advantage of mounting the combine on the caterpillar tractor lies largely in the ease of manipulation and the short, quick turns which can be made. Also, the weight of the tractor and combine is spread over a considerable area of ground and hence does not pack the soil, both considerations of major importance in handling experimental work.—L. C. AICHER and A. L. HALLSTED, *Fort Hays Branch Experiment Station, Hays, Kansas.*

BOOK REVIEW

PLANT COMPETITION

An Analysis of Community Functions

By Frederic E. Clements, John E. Weaver, and Herbert C. Hanson. Pub. No. 398, Carnegie Institution of Washington. Pages 340. $3.25 in paper; and $4.25 in cloth.

This monograph gives an account of community processes as studied primarily at Lincoln and Weeping Water, Nebraska, with collateral studies at Santa Barbara, California. The outline of the subject matter is as follows:

History of the competition concept; studies of transplant cultures in subclimax prairies; transplant cultures in true prairies; supplementary studies of competition in the prairies; competition in the ecotone between woodland and prairie; competition in cultivated fields; the relative importance of the factors in competition; functional studies in control cultures; nature and rôle of competition; and bibliography.

The experimental studies of the nature of competition and the rôle of water, light, and nutrients as primary factors of competition are of especial interest to the agronomist and plant breeder. It is of much value to them to know the interaction of habitat and organism. The correspondence is so close that the experienced ecologist knows in advance what community will be found in freshwater, swamp, salt-marsh, inland sandhills, or coastal dunes.

Various studies of the authors show "that competition and functioning of the individual stand in the most intimate reciprocal relation to each other. Absorption, transpiration, photosynthesis, chemosynthesis, and respiration all affect the physical factors of the habitat directly, producing reactions that determine the cause, intensity, and outcome of competition."—(M. C. S.)

AGRONOMIC AFFAIRS

LIST OF REFERENCES ON SUNFLOWER

A list of references on the sunflower (*Helianthus annuus*) is now available in mimeographed form from the U. S. Dept. of Agriculture Library. The list was compiled by Marjorie F. Warner, Bibliographer of the Bureau of Plant Industry Library. The material has been arranged under the general headings of Cultivation and Utilization, Breeding and Heredity, Botany, and Diseases, Insects, etc., and includes titles both in American and foreign literature. An author index is appended.

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GRASS AND TIMBER SOILS DISTRIBUTION IN THE BIG HORN MOUNTAINS[1]

T. J. DUNNEWALD[2]

The Big Horn Mountains cover about 21 townships of area in the west end of Sheridan County, Wyoming. These mountains rise abruptly from an elevation of 5,000 to 6,000 feet and extend to elevations of 9,000 to 10,000 feet. The Big Horn range has a northwest-southeast trend and the top of the range is an undulating series of hills and valleys and occasional rocky canyons and ridges.

On the east side of the range, pine timber covers the mountains practically down to the alluvial fans which issue from the front range and slope downward between the stream valleys to the east and southeast. On the west side timber growth commences at about 8,000 feet elevation and at 5,500 feet on the east side.

On top of the range, the pine timber covers the ridges, knolls, and areas of rocky shallow soil to the extent of about two-thirds of the total area. Undulating slopes and meadows to the extent of approximately one-third of the total area are covered largely with grass vegetation, with a small percentage of sage, and with low brush vegetation.

There appears to be no transition zone of bush or small trees between the timbered and grass areas. The line of demarkation is very sharp. General observation reveals that the areas occupied by timber are usually more stony with a shallow soil cover. The soil in the timbered areas is yellowish or grayish brown. On the grass areas the soil is generally much deeper and darker in color. The prevailing soil color in the grass lands is dark brown to black.

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[1] Contribution from the Department of Agronomy, Wyoming Agricultural Experiment Station, Laramie, Wyoming. Received for publication December 26, 1929.

[2] Assistant in Soil Investigations.

The change in soil color is just as sharp as the vegetation line, 1 or 2 rods distance marking the passage from dark brown or black grass land soil to gray or yellow brown timber soil.

Authoritative opinion from a soils point of view[3] is that brown timber soils develop from dark-colored grass prairie soils and mature into gray ash-like (Podsol) soils This process is characterized by an increase of acidity, removal of basic and organic materials, and a partial concentration of clays, iron, and alumina in the subsoil or B horizon with a concentration of silica in the surface or A horizon. The leaching process also produces progressively poorer soil so that the gray timbered soils are inherently less productive than the dark grassland soils.

This process of soil development from a continental point of view has been associated with climatic factors, partly temperature, but chiefly rainfall and vegetation. On a smaller area such as this, with its intimate association of small grass prairies and densely timbered tracts, it would seem that the climatic factors in the distribution of grass and trees must necessarily be reduced to a minimum.

Other factors than climatic variations must be largely responsible for the intimate mixture of dark and light soil and tree and grass vegetation in the Big Horn Mountains. An examination of these other possible factors is the purpose of this paper. The discussion and conclusions are treated from the point of view of "Pedology," or the science of the soil.

Neither variations in rainfall and temperature, distribution of rocks, nor differences in elevations seem to be a satisfactory explanation of the soil and vegetation distribution on the top of the range.

RAINFALL AND TEMPERATURE

Data from six stations in and near the Big Horn Mountains area show that the rainfall ranges from 4.48 inches at Hyattville at an elevation of 4,600 feet to 11.88 inches at Barnum at 5,500 feet, 16.19 inches at Alta at 6,500 feet, 19.4 inches at Hunters at 7,400 feet, 24.79 inches at Dome Lake at 8,821 feet, and 27.71 inches at Kirwin at 9,187 feet. The mean annual rainfall increases at the average rate of 0.5 inch per hundred feet of elevation. The mean annual temperature decreased from 46° at 4,600 feet to 30° at 9,200 feet, or at the rate of 3.5 degrees per thousand feet of elevation. Grass and timber areas are found at all of these elevations.

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[3] Lectures of C. F. Marbut and Glinka on the soils of Russia.

DISTRIBUTION OF ROCKS

The chief types of rocks found are the Madison, Big Horn, and Amsden limestones, the Deadwood sandstone, and granite. On the north end of the forest reserve timber covers the limestone areas in solid bodies, while only patches of timber occur on the Deadwood and granite formations. On the central and southern part of the forest, large bodies of timber cover the granite and sandstone areas and the glacial drift and moraines derived from these rocks For the area as a whole, it may be said that timber occupies most extensively the basic rocks, while grass covers mainly the acid sandstones and granite. General observations lead to the conclusion that shallow, stony soil on the harder rocks suits the pines, while grass prefers the deeper soils on the softer rocks.

ELEVATIONS

Large bodies of timber occur on granite at 8,000 to 9,500 feet, on sandstone at 8,500 to 9,000 feet, and on limestones at 7,000 to 9,000 feet. Grass lands cover extensive areas on granite rocks at 7,500 to 11,000 feet, on sandstones at 8,000 to 9,000 feet, and on limestones at 7,000 to 9,500 feet. Travel over the area does not give the impression that either timber or grass are confined to knolls, since both occur abundantly on knolls and ridges and also in valleys and swale areas.

SOIL REACTION AND ORGANIC MATTER

As stated before, the grass soils were found to be darker in color than the timbered soils. The dark color increases with elevation and with increased rainfall.

From the analytical data in Table 1 it will be seen that the grass areas are in some cases acid and in others basic in reaction. This is also true of the timbered areas, although the basic timbered soils have a more nearly neutral reaction

Disregarding the surface half inch accumulation of needles and twigs in the timbered areas, the average difference in organic matter content of the soil zones beneath grass and timber is not great. A more significant difference exists probably in the greater depth of penetration of organic matter under grass and in the more colloidal character of the prairie organic matter which gives the soil a darker brown to black color than in the timbered areas.

The basic grass soils have more nitrogen in their humus than the acid grass soils do. This relation is not as consistent in the organic matter of the timber soils as shown by the nitrogen-carbon ratio in Table 1.

TABLE 1.—*Composition of prairie grass and timbered soils, Big Horn Mountains.*

Profile	Soil No.	Color	Loss on ignition %	N %	pH	Fe, Al, P oxides %	Ca, Mg oxides %	N-C* ratio
			Grass Areas					
A_0	107	Light brown	4.86	0.081	7.0	4.17	0.56	1:30
A_1	108	Sage	4.08	0.077	7.2	5.83	0.52	1:25
A_2	109	——	3.91	0.087	7.7	5.69	0.53	1:22
B	110	Soil	3.53	0.078	7.8	5.97	3.02	1:22
C	111	Basic	2.70	0.042	8.4	8.98	14.01	1:33
A_0	112	Very dark	13.43	0.346	7.0	4.11	1.11	1:20
A_1	113	Brown	4.87	0.127	7.4	5.36	0.97	1:18
A_2	114	Sage	4.19	0.097	7.7	2.25	1.76	1:21
B	115	Basic	1.62	0.086	7.7	4.04	24.20	1:10
C	116	——	1.59	0.043	8.7	5.34	12.80	1:20
A	4	Grayish brown alluvial fan	13.4	0.41	8.5	9.56	4.20	1:16
B	5	Grass, basic	11.4	0.21	8.5	5.44	3.74	1:27
A_0	10	Dark brown	18.01	0.264	6.2	2.41	1.05	1:35
A_1	11	to black acid	9.9	0.129	6.1	2.45	0.61	1:37
B	12	Prairie grass	7.0	0.039	7.3	3.02	0.79	1:87
C	13	——	5.8	0.005	7.0	3.93	1.00	1:58
A_0	117	Brownish	38.75	0.420	6.0	4.04	2.16	1:46
A_1	118	Gray sage	5.74	0.374	6.0	5.96	0.68	1:8
B	119	Acid	5.29	0.103	6.1	7.72	0.39	1:26
C	120	——	3.17	0.031	6.1	7.90	0.22	1:53
			Timbered Areas					
A_0	1	Alluvial fan	72.4	0.182	7.0	1.89	3.23	1:190
A_1	2	Timbered	18.8	0.175	6.9	3.64	1.83	1:55
B	3	Basic	10.6	0.047	7.6	4.17	4.58	1:106
A_0	6	Dark gray	7.27	0.067	6.5	5.85	0.16	1:49
A_1	7	Brown	3.67	0.026	6.0	3.30	0.00	1:91
B	8	Acid	2.19	0.016	6.0	2.48	0.00	1:79
C	9	Timber	1.50	0.007	5.9	0.68	0.17	1:75
A_0	121	Brownish	7.23	0.277	6.0	1.60	1.64	1:13
A_1	122	Gray timber	5.81	0.148	5.8	5.69	0.56	1:29
A_2	123	Acid	3.56	0.057	6.0	4.44	0.19	1:29
B	124	——	2.65	0.032	6.0	8.31	0.42	1:44
C	125	——	2.69	0.016	5.8	8.39	0.19	1:67

*Carbon figured as 50% of ignition loss.

Since invasion of a prairie soil by timber results in increased acidity and losses of basic materials and organic matter, the interesting question occurs, "Will timber invade basic soil and, if not, how acid and low in bases must a soil become in order to encourage invasion by trees?"

With this question in mind, two sites were selected where timber and grass boundaries were very distinct, one at 9,500 feet elevation with high rainfall and acid soils, and another at 5,500 feet at the lower edge of the timber line with reduced rainfall and soils of limestone derivation. The sites may be described as follows:

Site A.—Sec. 32, T. 56-88 west on Dayton Kane Highway. Large pine 10 to 14 inches in diameter, nearly level land. Profile A_0 (0–½ inch) dark brown spongy pine needles; A_1 (½–2 inches) dark gray-brown friable silt loam; A_2 (2–8 inches) pale gray yellow loam; B (8–16 inches) compact yellow loam with scattered sandstone fragments; and C (16–24 inches) yellowish sandstone.

The open grass area, 10 rods distant, is a dark brown loam to silt loam A_0 (0–8 inches) on yellow brown loam; A_1 (8–12 inches) on yellow brown clay; B (12–16 inches) on yellow loamy sand; and C (16–36 inches) with sandstone at 36 inches. Slightly higher and more undulating than the timber area above.

Site B.—An alluvial fan of shallow limestone soil containing many limestone and sandstone fragments. The pine timber had invaded the edge of the open grass fan from the rocky slopes and canyon at the side. Timber 25 to 30 feet high about 40 years old covered 10 to 15 rods of the top of the fan. Profile of soil consists of pine needles and matted organic matter A_0 (0–1 inch) on gray brown loam to silty clay loam; A_1 (1–3 inches) with reddish brown compact clay loam to clay subsoil; and B (3–12 inches) containing many flat limestone fragments. Lodge pole and long leaf trees 40 years old.

The open grass sample, 5 rods east of the above, consists of brown to dark brown silty loam A (0–6 inches) on light brown compact silt loam with many limestone fragments, and B (6–12 inches). This represents a large area of open grass, steeply sloping alluvial fan soil.

The grass and timber distribution in the Big Horn forest is shown in Fig. 1.

Analyses of samples from the different horizons of these two sites are given in Table 2.

TABLE 2.—*Soil analyses from sites A and B.*

Soil No. and profile	Moisture %	Organic matter %	N %	Fe and Al oxides %	Ca and Mg oxides %	pH	N-C ratio
Site A, Acid Soils at 9,500 Feet							
Gray brown timber:							
No. 6 (0–½ inch) A_0	1.30	7.27	0.067	5.85	0.16	6.5	1:49
No. 7 (½–2 inches) A_1	0.65	3.67	0.026	3.30	0.00	6.0	1:91
No. 8 (2–8 inches) A_2	0.39	2.19	0.016	2.48	0.00	6.0	1:79
No. 9 (8–16 inches) B	0.39	1.50	0.007	0.68	0.17	5.9	1:75
Dark brown grass:							
No. 10 (0–8 inches) A_0	1.92	18.01	0.264	2.41	1.05	6.2	1:35
No. 11 (8–12 inches) A_1	1.76	9.90	0.129	2.45	0.61	6.1	1:37
No. 12 (12–16 inches) B	1.61	7.00	0.039	3.02	0.79	7.3	1:87
No. 13 (16–36 inches) C	1.21	5.80	0.005	3.93	1.00	7.0	1:58
Site B, Basic Soils on Alluvial Fan							
Gray brown timbered:							
No. 1 (0–1 inch) A_0	6.40	72.4	0.182	1.89	3.23	7.0	1:190
No. 2 (1–3 inches) A_1	3.10	18.8	0.175	3.64	1.83	6.9	1:55
No. 3 (3–12 inches) B	2.00	10.6	0.047	4.17	4.58	7.6	1:106
Brown loam open grass:							
No. 4 (0–6 inch) A	1.86	13.4	0.410	9.56	4.20	8.5	1:16
No. 5 (6–12 inches) B	2.80	11.4	0.210	5.44	3.74	8.5	1:27

These analyses show that timber will invade either a basic or an acid soil. Acidity is not a prerequisite for timber invasion, although the trees tend to increase the acidity or reduce the basicity by their presence. Lime and magnesia tend to disappear under timber growth. Iron and alumina show a tendency to be concentrated in the A horizons of the *acid soil* under timber and to move downward under grass. Grass and trees reverse this process on the *basic soil*.

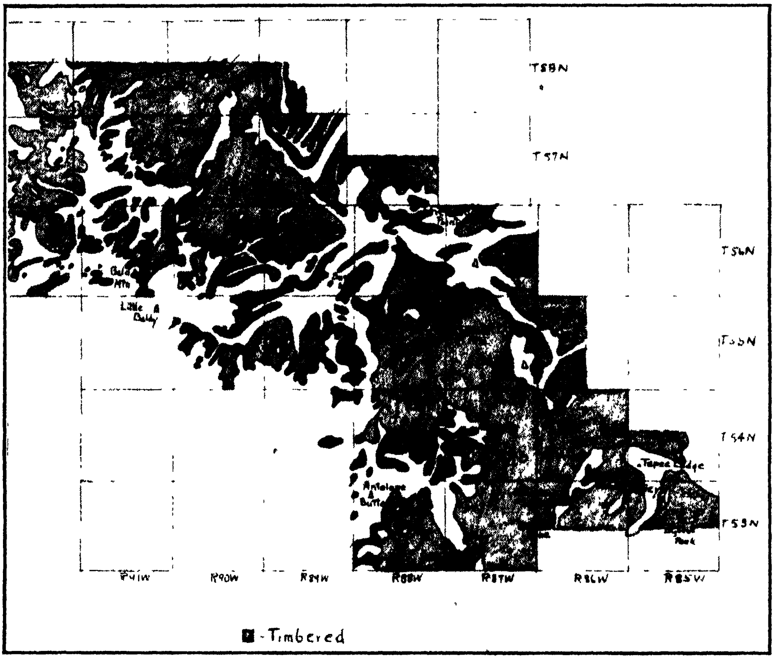

FIG. 1.—Grass and timber distribution in Big Horn Forest, Sheridan, Wyoming.

The presence of lime and a basic reaction favors the development of greater amounts of organic matter in both grass and timber soils. It is this organic matter which is chiefly concerned in the leaching movement of minerals and podsolization of timbered soils. The only factor that can be definitely assigned as a cause or reason for timber invasion in these two sites is that the timbered areas have, in general, a thinner, more stony, drier, and poorer soil. A previous paper[4] shows that the timbered soils have a smaller content of available phosphorus than have the grass soils. A recent paper[6] on pasture flora shows that pasture grass associations and timber vegetation can be correlated with available plant food in the soils

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[4] DUNNEWALD, T. J. Available phosphorus of soil resulting from moisture and temperature variations, Big Horn Mountains, Wyoming. Jour. Amer. Soc. Agron., 21:934-936. 1929.

The value to sheep and cattle of grasses grown on various soils depends upon the amount and kind of plant food available in the soil. Plenty of soft elements, such as Ca, N, and P, and the ability of the soil to produce nitrates, makes the most valuable type of pasture grass, while acidity and the harder elements in soil, such as Mg, Al, Mn, Fe, and Si, produce harder, less nutritious feed. Weeds, ferns, moss, and trees take the still less desirable soils.

The comparative value of grazing lands in the mountains on this basis would be about as follows. (1) Moist grass valleys and swales, black, deep, basic or neutral soil; (2) grass knolls, ridges and hills, black, deep, basic or neutral soil; (3) brown or yellow acid soils, scattered trees or brush; and (4) shallow, stony, timbered areas, acid soil.

When forest trees invade a grass prairie soil, the leaves or the needles and cones of the trees are deposited on the surface of the soil. The leachings from this surface organic matter penetrate the soil and bring a certain amount of material into solution which is redeposited in lower soil layers or carried away in the drainage waters

When grass sod develops on a soil, the main addition of organic matter is by means of the fine root systems which become intimately mixed with the soil Any solubility effects due to penetration of moisture in the grass soil are brought about in the intimate presence of both organic matter and soil which is a different situation than where the moisture must pass through the organic matter before penetrating the soil.

The degree and kind of solution which results should depend upon a number of factors, *one* of which would be *the kind of organic matter concerned*. Five grams of dark brown to black acid prairie soil were mixed with an equal amount of each of four kinds of organic matter, namely, green alfalfa leaves, spruce needles, deciduous leaf mold, and sphagnum moss. The first and last of these were acid or raw humus materials, while the leaf mold was sweet humus produced on basic soils. The soil and organic matter were brought slowly to a boil in beakers with 100 cc of distilled water on a hot plate for 1 hour. They were then filtered and the dissolved materials were determined in the filtrates. The results are shown in Table 3. It will be seen that the raw humus caused solution of more material, both mineral and organic, than did the mild or sweet humus.

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[6] COOPER, H. P., WILSON, J. K., and BARON, J. H. Ecological factors determining the pasture flora in the northeastern United States. Jour. Amer. Soc. Agron., 21: 607–627 1929.

TABLE 3.—*Material brought into solution by mixing organic matter with dark, acid, grassland soil.*

	Material soluble in 100 cc of water			
5 grams of dark prairie soil and	Total solids, grams	Organic matter, grams	Fe, Al, P oxides, grams	Ca and Mg oxides, grams
5 grams green alfalfa leaves	0.1079	0.0602	0.0078	0.0062
5 grams spruce needles	0.1021	0.0788	0.0065	0.0056
5 grams leaf mold (basic)	0.1361	0.0784	0.0152	0.0179
5 grams sphagnum moss	0.2658	0.2085	0.0080	0.0039

Leaf mold humus brought most mineral matter into solution when boiled with this soil, while the sphagnum moss treatment produced most soluble organic matter. Spruce needles and alfalfa leaves had a very similar action on both mineral and organic matter.

TABLE 4. *Material brought into solution by mixing organic matter with a gray basic subsoil*

	Soluble in 100 cc of water			
5 grams of basic subsoil and	Total solids, grams	Organic matter, grams	Fe, Al, P oxides, grams	Ca and Mg oxides, grams
5 grams green alfalfa leaves	0.1081	0.0511	0.0024	0.0032
5 grams spruce needles.. .	0.1202	0.0918	0.0013	0.0108
5 grams leaf mold (basic)	0.1163	0.0625	0.0110	0.0204
5 grams sphagnum moss	0.7292	0.5348	0.0193	0.0089

From the high lime subsoil (Table 4), most mineral matter was released by leaf mold and sphagnum moss. Spruce needles released considerable lime also, otherwise the alfalfa leaves and spruce needles reacted similarly on mineral matter. Sphagnum moss treatment released most organic matter, with spruce needles second

Comparison of the totals on the two soils seems to indicate that iron, aluminum, and phosphorus are brought into solution most largely in the acid prairie soil, while calcium and magnesium go more largely into solution in the high lime soil. A second factor influencing the results of contact between organic matter and soil would be *the kind of soil* concerned.

A *third* factor in the result of soil-organic matter contact would be the *position* of the organic matter. What difference in the amounts and kinds of materials going into solution occurs when the organic matter lies on top of the soil instead of being intimately mixed with it? To simulate this situation, 5 grams of each kind of organic matter were brought to a boil with 100 cc of distilled water for 1 hour, filtered, and 5 grams of the soils digested 1 hour with the water extracts of organic matter. The materials dissolved from the acid and basic soils by the two methods are shown in Tables 5 and 6.

It will be seen that organic matter decreases slightly and that iron, aluminum, and phosphorus increase in rate of solubility when the organic matter is placed on top of the acid dark prairie soil instead of being mixed with it, but little effect is noted on the calcium and magnesium. The organic matter reacts similarly on the high lime soil, but the result is opposite in the case of iron, aluminum, and phosphorus, which show reduced solubility, and in the case of calcium and magnesium, which show increased solubility with organic matter placed on top of the soil.

On the basis of these results, we should predict that the invasion of dark, acid prairie soil by timber would result in increased solution and movement of iron, aluminum, and phosphorus, while the invasion of a high lime soil would result in solution and removal of less iron, aluminum, and phosphorus but of more calcium and magnesium.

TABLE 5 *Comparison of materials made soluble in dark prairie soils where the organic matter is mixed with the soil and where the organic matter extract alone is used with the soil*

5 grams of soil and	Total solids, grams	Organic matter, grams	Fe, Al, P oxides, grams	Ca and Mg oxides, grams
5 grams green alfalfa leaves	0.1079	0.0602	0.0078	0.0062
Extract of 5 grams alfalfa leaves	0.1761	0.1244	0.0165	0.0070
5 grams spruce needles	0.1021	0.0788	0.0065	0.0056
Extract of 5 grams spruce needles	0.0924	0.0699	0.0105	0.0062
5 grams leaf mold.	0.1361	0.0784	0.0152	0.0179
Extract of 5 grams leaf mold	0.1007	0.0631	0.0067	0.0152
5 grams sphagnum moss	0.2658	0.2085	0.0080	0.0039
Extract of 5 grams sphagnum moss	0.1420	0.1017	0.0195	0.0061

There seems to be a general decrease of solubility of organic matter when it is not mixed intimately with the prairie soil and a general increase in solution of the iron, aluminum, and phosphorus There is little or no difference in the amounts of calcium and magnesium brought into solution.

TABLE 6.—*Comparison of materials made soluble in basic subsoil where the organic matter is mixed with the soil and where the organic matter extract alone is used with the subsoil.*

5 grams of soil and	Total solids, grams	Organic matter, grams	Fe, Al, P oxides, grams	Ca and Mg oxides, grams
5 grams green alfalfa leaves	0.1081	0.0511	0.0024	0.0032
Extract of 5 grams alfalfa leaves	0.2237	0.1558	0.0102	0.0141
5 grams spruce needles	0.1202	0.0918	0.0013	0.0108
Extract of 5 grams spruce needles	0.0713	0.0566	0.0035	0.0086
5 grams leaf mold	0.1163	0.0625	0.0110	0.0204
Extract of 5 grams leaf mold	0.1073	0.0641	0.0044	0.0204
5 grams sphagnum moss	0.7292	0.5348	0.0193	0.0089
Extract of 5 grams sphagnum moss	0.1144	0.0841	0.0067	0.0117

On the high lime soil there also seems to be a slight average decrease of solubility of organic matter and a reduced solubility of iron, aluminum, and phosphorus when the organic matter is not mixed with the soil. Calcium and magnesium solubility is increased.

In other words, we may say that the advent of trees and the application of fresh organic matter to the surface of the soil, greatly stimulates the extraction of soluble materials, i. e., leaching. This leaching first removes calcium, magnesium, and organic matter from the basic soil, while iron, magnesium, and phosphorus are removed more rapidly when the soil is acid. Basic soil reaction tends to slow up the leaching of soluble materials from soil by organic matter.

SUMMARY

1. Grass vegetation in the Big Horn Mountains produces dark-colored acid soils with large amounts of colloidal black organic matter. When invaded by timber, the organic matter from the trees starts a leaching process which reduces the soluble organic and mineral content of the soil Timber will invade either acid or basic soil and its tendency is to increase the acidity of acid soil or to decrease the bases in a basic soil.

2. Timber invasion removes iron, aluminum, and phosphorous less rapidly and calcium and magnesium more rapidly from a basic soil than from an acid soil. This process makes acid timber soils less fertile and less productive grazing land than the grass soils of the mountain areas.

3. This difference in fertility is shown by the greater nitrogen content of the organic matter of the grass soils and by the greater amounts of available phosphates in them.

4. The data seem to show that the bases are more actively removed by organic matter placed on top of the soil than when intimately mixed with it. Iron, aluminum, and phosphorous are removed less rapidly under these conditions in the basic soil and more rapidly in the acid soil.

A WEED SURVEY OF IOWA[1]

L. H PAMMEL AND C. M. KING[2]

The purpose of the weed survey in progress in Iowa is to get an indication of the dominant weeds in different crops in the state. The study here presented is only preliminary to a more extensive survey. Representative illustrations have been selected for different crops, under different soil conditions and in various parts of Iowa, a previous paper reports on weeds of Story County [3]

It is well known that certain types of weeds are characteristic of certain soils. For instance, it is quite universal to find that the flowering spurge, *Euphorbia corollata*, is a weed common to sandy soils, although frequently it is more or less abundant in crops in regions where Buckner soil abounds and is also common in the type of soil in which there is little mixture of sand but is less common than on the Buckner silt loam Again, the common sheep sorrel, *Rumex Acetosella*, is abundant in acid soils everywhere in the state, and therefore is found in the Wisconsin drift where some of these acid, sandy soils occur.

Again, certain types of weeds are closely associated with certain crops, for instance, the corn cockle, *Agrostemma Githago*, the cow herb, *Saponaria Vaccaria*, and cheat or chess, *Bromus secalinus*, are commonly associated with the wheat crop, and it may be interesting to note that over a large area of Iowa where wheat is no longer the prevailing crop some of these weeds have disappeared or are rarely found.

It is generally true that the predominating weeds of corn fields are the green and the yellow fox-tails, *Setaria viridis* and *S. glauca*, respectively. They are commonly associated with heart's ease, *Polygonum pennsylvanicum*, and barnyard grass, *Echinochloa crusgalli*. It may be of interest also to note that water hemp, *Acnida tuberculata*, is not so common as *A. tamariscina*. The former is the prevailing weed in the southern part of the state. Also, such weeds as the horse nettle, *Solanum carolinense*, which is a migrant from the south, are much more abundant in the grain fields in southern Iowa. The shoofly, although native to Europe, seems to have gotten a much stronger foothold in southern than in northern Iowa. Again, such weeds as the common sunflower, *Helianthus annuus*, and the marsh elder, *Iva xanthifolia*, are western weeds which are migrating eastward and becoming dominating weeds in corn and some grain fields. The most abundant weed of the fields next to the foxtail, but one which seldom does much damage, is mustard. The most common form in southern Iowa seems to be the Indian mustard, *Brassica juncea*, but in northern Iowa common mustard, *B. arvensis*, is more common.

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[1] Contribution from the Department of Botany, Iowa State College, Ames, Iowa. Received for publication December 30, 1929.

[2] Chief Botanist and Assistant Chief Botanist, respectively.

[3] PAMMEL, L. H., and KING, C. M. Weed survey of Story County. Proc. Iowa Acad. Sci., 21: 115–118. 1914.

A study of pastures reveals the fact that the most common and troublesome weed in the state is the small ragweed, *Ambrosia artemisiifolia*, probably occurring in more than 75% of the pastures. Its abundance is probably due to the fact that the weed is distasteful to stock. Another quite common pasture weed is the blue vervain, *Verbena stricta*, especially in northern Iowa; but here again, the distasteful properties of the weed is the reason for its abundance.

Greater care has been used in the extermination of some weeds, thus, formerly the bull thistle, *Cirsium lanceolatum*, was a common weed in pastures. It is far less common today than it was 10 years ago. It is rather interesting to note that certain types of weeds are especially common in red and alsike clover fields. Of these might be mentioned the wild carrot, *Daucus Carota*, buckhorn, *Plantago lanceolata*, and the bracted plantain, *P. aristata*.

In meadows certain types of weeds are more or less common like peppergrass, *Lepidium virginicum*, five finger, *Potentilla monspeliensis*, and the two common plantains, *Plantago major* and *P. Rugelii*.

Certain plants are more or less abundant in oat fields. Several years ago the marsh cress, *Radicula palustris*, was a very abundant plant over a vast region due altogether to the method of cultivation of corn. This weed is a winter annual, consequently when oats are sown on corn stubble it has every opportunity to become common. Much depends upon the germination of the seed the previous season.

Cockleburs, *Xanthium* sp., are very much less abundant than they were a few years ago, while catchfly, *Silene noctiflora*, and *Lychnis alba* and *L. vespertina* are on the increase.

Many weeds are more or less cosmopolitan, and soil makes very little difference with them. This is true of purslane, *Portulaca* sp., lamb's quarters, *Chenopodium album*, and the fox-tails, *Setaria* sp., and crowfoot grass, *Elusine indica*.

The weed problem is one of the most important problems in Iowa. More money is spent in destroying weeds than in any other one phase of crop production, and in many cases one more cultivation of the corn crop may make a difference in yield of from 10 to 15 bushels of corn to the acre.

TABLE I.—*Weeds observed in fields and roadsides in Marion and Jasper Counties, Iowa, showing percentage of fields in which the weeds were present.**

Names of plants	Marion County oat field	Marion County pasture	Marion County timothy meadows	Marion County roadside	Jasper County oat field	Jasper County oatfield border	Jasper County timothy	Jasper County pastures
	%	%	%	%	%	%	%	%
Mustard (*Brassica juncea*) .	30	—	—	—	50	—	—	—
Dogbane (*Apocynum cannabinum*).	50	—	—	—	—	—	—	—
Milkweed (*Asclepias syriaca*)....	60	—	—	P†	100	—	—	—
Velvetweed (*Abutilon Theophrasti*).	40	—	—	P	—	—	—	—
Great ragweed (*Ambrosia trifida*)... .	40	40	40	P	—	50	—	—
Hedge bindweed (*Convolvulus sepium*)	40	—	—	—	—	—	—	—
Artichoke (*Helianthus tuberosus*)...	—	100	—	P	—	—	—	—
Squirrel tail grass (*Hordeum jubatum*).	—	30	—	P	—	—	—	25
Blue vervain (*Verbena stricta*) ..	—	70	—	P	—	—	—	100
White vervain (*V. urticaefolia*)	—	20	—	P	—	—	—	25
Dandelion (*Taraxacum officinale*) .	—	100	—	P	—	—	—	—
Whiteweed (*Erigeron annuus*).	—	70	70	P	—	—	100	—
Horseweed (*E. canadensis*)... .	—	50	50	P	—	—	100	—
Prickly lettuce (*Lactuca scariola*)....	—	100	100	—	—	—	—	—

*L. H. Pammel, observer, 1928.

†Signifies presence of weed.

TABLE 2.—*Percentages of different weeds found in various fields in several counties in Iowa, 1928.**

Name of plant	Mahaska County (Oskaloosa)			Jasper County (d, Newton; f, Prairie City)				Hancock County (Garner)		Cherokee County						Webster County (Fort Dodge)	Page County (Essex)	Greene County (Jefferson)		Montgomery County (Red Oak)		Crawford County (Denison)	
	Oat field	Pastures, loamy near woodland	Border weeds, b	Pastures, thin	Border weeds, d	Red clover field	Border weeds, f	Corn, sandy drift	Border weeds, h	Corn, upland drift	Border weeds, j	Corn, bottom land	Border weeds, l	Alfalfa	Border weeds, n	Alfalfa, 2nd crop	Alfalfa, 2nd crop	Corn, prairie	Border weeds, r	Alfalfa	Border weeds, u	Oat field	Border weeds, v
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w
Setaria viridis	42.8	—	P†	—	—	8.30	P	27.07	P	16.00	P	58.9	P	36.00	P	10.30	15.50	12.60	P	—	–	5.2	P
Bidens vulgata	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	–	—	—	–	—	–	—	P
Setaria glauca	34.3	7.6	–	26.60	–	55 10	P	23.25	P	52.2	P	15.30	P	22.65	P	5.2	8.5	10.00	P	—	–	—	–
Brassica juncea	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	—	–	—	–	1.6	P
Polygonum pennsylvanicum	1.04	1.60	–	—	–	8.50	P	1.14	P	2.8	P	—	–	—	–	—	—	3.10	P	—	–	—	–
Chenopodium album	1.65	—	–	—	–	1.33	P	2.96	P	3.7	P	4.2	P	—	–	—	—	1.2	P	—	–	—	P
Erigeron canadensis	—	7.3	–	5.32	P	—	P	—	–	—	P	—	–	4.00	P	—	—	—	P	—	–	—	–
Abutilon Theophrasti	1.22	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	—	–	—	–	—	–
Acnida tamariscina	1.2	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	1.8	P	—	–	—	–
Hordeum jubatum	1.1	12.30	–	6.84	P	—	–	—	–	—	–	—	–	—	–	4.60	—	—	–	—	–	—	–
Hibiscus Trionum	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	0.66	P	—	–	—	–
Asclepias syriaca	1.0	—	–	—	P	0.84	P	0.5	P	—	–	—	–	—	–	—	—	1.00	P	1.5	P	0.6	–
Portulaca oleracea	—	—		—	–	—	–	—	–	—	–	—	–	—	–	5.2	—	1.6	P	—	–	—	P
Equisetum arvense	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	0.33	P	—	–	—	–
Melilotus officinalis	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	—	P	1.5	P	—	–
Polygonum acre	—	1.00	P	3.80	P	—	–	—	–	—	–	—	–	—	–	—	—	—	–	—	–	–	–
Verbascum Thapsus	—	—	–	—	–	—	–	—	–	—	–	—	–	—	–	—	—	—	–	—	P	—	–
Panicum dichotomiflorum	—	3.60	P	—	–	4.25	P	—	–	—	–	—	–	—	–	—	—	5.5	P	—	–	—	–

Echinochloa crus-galli	—	2.00	-	—	-	6.20	P	12 54	P	—	-	8.7	P	11.00	P	—	—	19.2	P	7.5	P	—	P
Verbena hastata	—	—	P	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Polygonum lapathifolium	—	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	P	—	-
Oenothera biennis	—	—	P	—	-	—	P	—	-	—	P	—	P	—	-	—	—	—	-	—	-	—	-
Cirsium discolor	—	—	P	—	-	—	-	—	-	—	P	—	-	—	-	—	—	—	-	—	-	—	-
Panicum capill-ri	—	—	P	—	-	—	-	—	-	—	-	—	-	—	-	—	—	3.00	P	—	—	—	-
Eragrostis major	—	—	P	—	-	1.33	P	2.40	P	—	P	—	-	—	-	—	—	0.66	P	—	-	—	-
Erigeron divaricatus	—	—	-	5 32	P	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Digitaria humifusa	—	—	-	11 40	P	5.00	P	1.71	P	—	-	—	-	—	-	—	—	3.10	P	—	-	—	-
Plantago Rugelii	—	—	-	3.8	P	—	-	—	-	—	-	—	-	—		22 0	6.2	—	-	—	-	—	-
Polygonum aviculare	—	—	-	3.8	P	—	P	—	-	—	-	—	-	—	-	—	—	—	P	—	-	—	-
Lepidium apetalum	—	—	-	1.52	P	—	P	—	-	—	-	—	-	—	-	—	—	—	P	—	-	—	-
Vernonia Baldwinii	—	—	-	1.52	P	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Verbena bracteosa	—	—	-	—	-	—	-	—	-	—	-	—	-	4 00	P	—	—	—	-	—	-	—	-
Solidago canadensis	—	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	1 50	—	-	—	-	—	-
Eragrostis pilosa	—	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	0.66	P	—	-	—	-
Lepidium virginicum	1.1	—	-	1 90	P	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Sisymbrium officinale	1.0	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Anthemis Cotula	0.8	1.60	P	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Ambrosia trifida	0.3	—	-	—	-	42	P	—	P	—	P	—	P	—	-	—	—	—	P	—	-	0 6	P
Amaranthus retroflexus	0.3	1.20	P	—	-	—	-	1 25	P	—		—	-	—	-	5 10	8 50	0 66	P	—	-	—	-
Verbena stricta	0.3	3.60	P	—	-	—	-	—	-	—	P	—	-	8.20	P	—	—	—	P	—	-	—	-
Rumex altissimus	—	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	P
Physalis pubescens	0.31	—	-	—	-	—	-	—	-		-	—	-	—	-	—	—	1 0	P	—	-	—	-
Lactuca scariola	0.22	—	-	—	P	—	-	—	-	—	P	—	P	—	-	—	—	—	-	—	-	—	-
Achillea lanulosa	c.15	—	-	—	-	—	-	—	-	—		—	-	—	-	—	1 5	—	-	—	P	—	-
Rumex crispus	0.15	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Malva rotundifolia	0.15	—	-	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Ambrosia artemisiifolia	—	50.60	P	1 90	P	2.50	P	1.25	P	—	-	—	P	10 00	P	—	—	0.66	P	—	-	—	-
Erigeron annuus	—	0.66	P	—	-	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-
Cirsium lanceolatum	—	0.34	P	—	-	—	-	—	-	—	-	—	-	—	-	12.00	4.50	—	-	—	-	—	-
Taraxacum officinale	—	6.60	P	13.30	P	—	-	—	-	—	-	—	-	—	-	—	—	—	-	—	-	—	-

*L. H. Pammel, observer. (Thelma Hawkins: q, r, t and w; L. H. Pammel and I. D. Butler: v and w.)

†Signifies presence of weed.

TABLE 2.—*Concluded.**

Name of plant	Mahaska County (Oskaloosa)			Jasper County (d, Newton; f, Prairie City)				Hancock County (Garner)		Cherokee County						Webster County (Fort Dodge)	Page County (Essex)	Greene County (Jefferson)		Montogomery County (Red) Oak)		Crawford County (Denison)	
	Oat field	Pastures, loamy near woodland	Border weeds, b	Pastures, thin	Border weeds, d	Red clover field	Border weeds, f	Corn, sandy drift	Border weeds, h	Corn, upland drift	Border weeds, j	Corn, bottom land	Border weeds, l	Alfalfa	Border weeds, n	Alfalfa, 2nd crop	Alfalfa, 2nd crop	Corn, prairie	Border weeds, r	Alfalfa	Border weeds, u	Oat field	Border weeds, v
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w
Melilotus alba	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3.10	6.50	—	—	—	—	—	—
Trifolium pratense	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.00	2.50	—	—	—	—	—	—
Lychnis alba	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11.00	3.50	—	—	—	—	—	—
Digitaris sanguinalis	—	—	—	—	—	—	—	—	P	1.80	P	—	—	—	—	—	—	—	—	—	—	—	—
Muhlenbergia mexicana	—	—	—	—	P†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pastinaca sativa	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bidens frondosa	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heliopsis scabra	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Helianthus grosseserratus	—	—	—	—	—	—	—	—	P	—	P	—	P	—	—	—	—	—	P	—	—	—	—
Gaura biennis	—	—	—	—	—	0.66	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Convolvulus sepium	—	—	—	—	—	3.00	P	—	—	6.30	P	0.99	P	—	—	—	—	—	—	3.3	P	0.2	P
Polygonum Muhlenbergii	—	—	—	—	—	1.33	P	3.42	P	—	—	7.2	P	—	—	—	—	—	—	—	—	—	P
Euphorbia Preslii	—	—	—	—	—	0.84	P	—	—	—	—	—	—	0.72	P	—	—	4.00	P	—	—	0.2	P
Radicula Armoracia	—	—	—	—	—	0.30	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Capsella Bursa-pastoris	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Acnida tuberculata	—	—	—	—	—	—	—	2.05	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Euphorbia serpyllifolia	—	—	—	—	—	—	—	6.80	P	2.8	P	—	—	1.92	P	—	—	2.40	P	—	—	—	—
Solanum nigrum	—	—	—	—	—	—	—	1.14	P	—	—	—	—	—	—	—	—	—	—	4.2	P	—	—
Polygonum Convolvulus	—	—	—	—	—	—	—	1.71	P	—	—	—	—	—	—	6.00	—	—	—	4.5	P	—	—

Euphorbia maculata	—	—	—	—	—	—	—	1.51 P*	—	—	3.00′ P*	—	—
Sonchus oleraceus	—	—	—	—	—	—	—	—	—	2.5′	—	—	—
Saponaria Vaccaria	—	—	—	—	—	—	—	—	—	—	—	3.5 P	—
Agropyron repens	—	—	—	—	9.92 P	—	—	—	—	—	—	—	—
Helianthus annuus	—	—	—	—	0.23 P	1 6 —	—	1 45 P	—	2 5	—	— P	42.7 P
Rosa pratincola	—	—	—	—	1 14 P	— P	—	—	—	—	—	—	—
Apocynum cannabinum	—	—	—	—	—	—	—	—	—	—	—	—	0.5 P
Helianthus tuberosus	—	—	—	—	0 45 P	—	1.70 P	—	—	—	—	—	—
Malva rotundifolia	—	—	—	—	0.22 P	—	—	—	—	—	—	—	—
Bidens discoidea	—	—	—	—	0 57 P	—	—	—	—	—	—	—	—
Xanthium commune	—	—	—	—	1 90 P	—	—	—	—	—	—	—	—
Brassica nigra	—	—	—	—	0 45 P	—	—	—	—	—	—	—	— P
Amaranthus blitoides	—	—	—	—	—	6 60 P	0 9 P	—	—	—	1.5 P	—	—
Salvia lancaefolia	—	—	—	—	—	—	—	—	—	—	—	—	—
Ipomoea purpurea	—	—	—	—	—	—	0 66 P	—	—	—	—	—	—
Cannabis sativa	—	—	—	—	—	— P	— P	—	—	—	—	— P	—
Iva xanthifolia	—	—	—	—	—	— P	— P	—	—	—	—	—	—
Solanum carolinense	—	—	—	—	—	— P	— P	—	—	—	—	3.2 P	—
Silphium perfoliatum	—	—	—	—	—	— P	— P	—	—	—	—	—	—
Bromus tectorum	—	—	—	—	—	— P	— P	—	1.5	—	—	—	—
Cirsium arvense	—	—	—	—	—	— P	—	—	—	—	—	—	—
Urtica gracilis	—	—	—	—	—	— P	— P	—	—	—	—	—	—
Cirsium canescens	—	—	—	—	—	— P	— P	—	—	—	0.5 —	—	—
Physalis lanceolata	—	—	—	—	—	—	—	—	—	4.60 P	—	—	—

*L. H. Pammel, observer. (Thelma Hawkins: q, r, t and w; L. H. Pammel and I. D. Butler: v and w.)

†Signifies presence of weed.

WEEDS OF SPECIAL CROPS

The abundance of weeds in meadows, pastures, and oat fields in Iowa was noted from a passing automobile, and the observations are recorded in Table 1.

The vast majority of weeds can easily be recognized from a little distance, although there may be some difficulty in distinguishing between *Lepidium apetalum*, and *L. virginicum; Brassica juncea, B. arvensis*, and *B. nigra; Digitaria sanguinalis* and *D. humifusa;* and *Plantago major* and *P. Rugelii.*

The prevalence of different kinds of weeds in various fields and adjacent borders was also noted for representative sections of the state. In obtaining percentage of weeds for each field, several scattered plats of equal size were taken and percentages of occurrence found for the different weeds. The results obtained are given in Table 2.

In an oat field observed in Mahaska County (Table 2), the field had been in corn the previous years and the oats were sown on corn stubble without plowing. Part of one field lay close to a hog lot, as indicated by the presence of *Anthemis Cotula.* The three dominant weeds were common foxtail, *Setaria viridis*, yellow foxtail, *S. glauca*, and heart's ease, *Polygonum pennsylvanicum.* All of these weeds were common border weeds.

In a red clover field in Jasper County (Table 2), the clover was growing on oat stubble on gently sloping land of an upland, Muscatine silt loam soil.

Along the roadside in Marion County, the following weeds were observed: Small ragweed, *Ambrosia artemisiifolia;* dog fennel, *Anthemis Cotula;* black mustard, *Brassica nigra;* meadow sunflower, *Helianthus grosseserratus;* awned brome grass, *Bromus tectorum;* whiteweed, *Erigeron strigosus;* wild parsnip, *Pastinaca sativa;* wild carrot, *Daucus Carota;* whorled milkweed, *Asclepias verticillata;* peppergrass, *Lepidium apetalum;* white spurge, *Euphorbia corollata;* cypress spurge, *E. Cyparissias;* evening primrose, *Oenothera biennis*; matrimony vine, *Lycium halimifolium;* yarrow, *Achillea lanulosa*; smartweed, *P. Persicaria;* shepherd's purse, *Capsella Bursa-pastoris*; common thistle, *Cirsium discolor;* bull thistle, *C. lanceolatum;* plantain, *Plantago Rugelii;* plantain, *P. major;* horse radish, *Radicula Armoracia;* and marsh cress, *Radicula palustris.*

ROOT RESERVES OF ALFALFA WITH SPECIAL REFERENCE TO TIME OF CUTTING AND YIELD[1]

C. J. WILLARD[2]

Investigations concerning the best stage of harvesting alfalfa were started at Columbus in 1925 primarily to answer the question, "How many cuttings of alfalfa are best in central Ohio?" Since it is obvious that any effect of cutting treatments on later yields must be through the roots in some way, roots as well as tops were harvested in order to follow the changes in amount of roots as they occurred throughout the season.

Yields of both hay and roots were secured by harvesting carefully selected representative square yard samples, duplicated always, and, in 1925, quadruplicated. The roots were harvested to a depth of approximately 1 foot, but were not trimmed to length after being dug in the field. The alfalfa was cut five, four, three, and two times each season. The first cuttings were made at bud stage, very early bloom, nearly full bloom, and early seed stage, respectively. The last cutting was made on the same date for all stages of harvesting, and the intervening time was arbitrarily divided but resulted in cutting at very nearly the stages just mentioned for the different cutting treatments throughout the season. Four other cutting treatments were also followed in 1926, 1927, and 1928.

Yields from square yard plats which are reported as below 1,000 pounds per acre were of such very short alfalfa that much of it would have been lost by machine harvesting. Above 1,500 pounds per acre the square yard yields check very closely with field yields. The hay yields secured, and the corresponding yields of roots, are given in Table 1. The yields in 1926, 1927, and 1928 were from the same plats, sown in 1925; while the yields in 1925 were from plats in a field sown in 1924, but not continued after June 1926. Table 2 gives the June 1926 yields on the 1925 plats.

The hay data have been previously published and discussed (5),[3] but the following practical points may be noted:

1. Cutting five times resulted in a total loss of stand from winter-killing on one series and a considerable decrease in yield the next year in the other. This system was impractical, even to secure extra quality hay.

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[1] Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Paper read as part of a symposium on "Alfalfa" at the meeting of the Society held in Chicago, Ill., November 14–15. 1929.

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[3] Reference by number is to "Literature Cited," p. 602.

2. Four cuttings resulted in higher yields of better quality hay than three cuttings the first year of cutting, but resulted in serious losses of stand and hence lower yields in succeeding years.

3. Cutting three times resulted in higher yields of hay and much better quality hay than cutting twice. The average loss from cutting only twice was 2,680 pounds of hay per acre, and the two-cutting hay averaged 1.5% of protein and 7.2% of leaves less than the three-cutting hay.

TABLE 1.—*Effect of number of cuttings of alfalfa on yields of hay and roots.*

No. and date of cutting	Pounds of hay per acre				Pounds of air-dry roots per acre			
	1925	1926	1927	1928	1925	1926	1927	1928
1st, May 16 and 28 .	3,320	2,730	——	——	1,600	1,080	——	——
2nd, June 17 and 28..	2,450	1,300	——	——	1,390	990	——	——
3rd, July 17 and 29 .	1,770	1,160	Dead	——	1,490	1,480	Dead	——
4th, Aug. 19 and 27 .	1,300	1,880	——	——	1,750	1,400	——	——
5th, Sept. 23 and 25.	930	940	——	——	1,680	1,040	——	——
Winter cover*......	(900)	(660)	——	——	1,900	1,250	——	——
Total hay.	9,770	8,010	——	——	——	——	——	——
1st, May 31 to June 7.	3,840	3,600†	2,620	2,310	1,510	——	1,130	1,520
2nd, July 6 to 13. ..	2,730	1,390	1,940	1,590	1,890	1,490	1,050	1,120
3rd, Aug. 9 to 20 ...	1,550	2,080	1,140	830	2,400	1,740	1,170	1,010
4th, Sept. 11 to 25 ..	1,280	1,650	780	330	2,540	1,660	1,300	1,020
Winter cover*.....	(1,080)	(960)	(1,340)	(290)	2,710	1,890	2,090	1,240
Total hay	9,400	8,720	6,480	5,060	——	——	——	——
1st, June 13 to 15 ..	3,710	4,020	4,970	3,640	1,630	1,750	1,820	2,200
2d, July 26 to Aug. 5..	2,260	1,840	3,200	3,380	2,220	1,580	1,620	1,770
3rd, Sept 11 to 25 ..	1,380	1,940	1,670	1,640	2,700	2,400	2,340	2,070
Winter cover*......	(1,310)	(1,390)	(2,030)	(1,340)	2,840	2,150	2,740	2,820
Total hay....	7,350	7,800	9,840	8,660	——	——	——	——
1st, June 26 to 28 ...	3,290	3,480	5,290	4,910	2,010	1,590	2,150	2,430
2nd, Sept. 11 to 25 ..	1,280	1,940	1,560	1,180	2,420	2,070	1,700	1,800
Winter cover*......	(1,340)	(1,160)	(1,390)	(960)	2,740	2,200	2,040	2,170
Total hay	4,570	5,420	6,850	6,090	——	——	——	——

*Not removed. †Estimated.

TABLE 2.—*Yields of alfalfa sown in 1924.*

Treatment in 1925	Pounds per acre, June 3-7, 1926	
	Hay	Roots
Cut 5 times..........	3,590	1,710
Cut 4 times.........	4,470	2,220
Cut 3 times.............................	4,650	2,570
Cut 2 times...........	4,300	2,270

These results are in general agreement with those of Salmon, *et al.* (4),[3] Kiesselbach and Anderson (3), and other investigators, except that, apparently due to diseases, stands of alfalfa are not as long lived in Ohio as west of the Mississippi. The literature of the subject has been thoroughly reviewed by these workers, and it does not seem necessary to repeat it here.

RELATION OF ROOT RESERVES TO HAY YIELDS

Table 1 shows that root reserves, as measured by the total weight of roots, are a definite factor in the yield of alfalfa. The five-cutting plat in 1926 is an example of extreme conditions. The roots on this plat were reduced to 1,250 pounds per acre. The growth for winter cover was extremely small, and nearly complete winterkilling from heaving followed.

Before this stage was reached, frequent immature cuttings reduced the vigor and amount of recovery after cutting somewhat in proportion to the total weight of roots present. This agrees with the data of Graber, *et al.* (2) Since most of the cuttings were made on different dates, there are not many directly comparable samples available, but the amount of winter cover in all the years, and the yields in June 1926 of the 1925 plats, are almost exactly in proportion to the weight of roots present at those times.

AT WHAT STAGE ARE ROOT RESERVES STORED?

Studies were made of the life history of alfalfa sown in the spring in a nurse crop from July of the seeding year until the end of June of the next year. The fall harvests have been sufficiently regular to average, and are presented in Table 3. The spring harvests are presented by years in Table 4.

TABLE 3.—*Development of alfalfa, first year.**

Date	Pounds per acre, air-dry Tops	 Roots
July 17	680	140
Aug. 1	680	200
Aug. 15	950	320
Sept. 1	1,310	530
Sept. 15	1,470	710
Oct. 1	1,660	990
Oct 15	1,560	1,050
Nov. 1	1,430	1,150

*3-year average, not clipped after cutting nurse crop.

TABLE 4.—*Development of alfalfa, spring of second year.*

Date	Pounds of roots per acre 1923	 1925	 1926	 1928	 1929
March 31	1,250 (2)*	—	—	—	—
April 12	—	—	—	—	840 (2)
April 24	1,070 (2)	—	—	—	—
April 27	—	—	—	—	1,020 (2)
May 4	—	—	710 (4)	—	—
May 10	1,040 (2)	—	—	630 (14)	—
May 11	—	—	—	—	1,330 (2)
May 15	—	1,440 (10)	—	—	—
May 24	1,350 (2)	—	—	—	—
May 25	—	—	—	—	1,490 (2)
May 30	—	1,520 (5)	1,120 (16)	1,020 (14)	—
June 10	—	—	—	—	1,450 (2)
June 12	—	1,660 (5)	1,560 (4)	—	—
June 14	1,410 (2)	—	—	1,350 (14)	—
June 25	—	2,010 (4)	—	—	—
June 26	—	—	1,590 (2)	—	—

*Figures in parentheses are number of samples averaged.

These data indicate that until the first cutting of a new seeding of alfalfa the roots develop along with the tops, except that there is a period of accumulation of root reserves in October and a slight loss as growth starts in the spring, noted only in 1923 in the data given. Graber, *et al.* (2) report that an important period of root storage in alfalfa is from full bloom to seed stage. Alfalfa is in full bloom at Columbus from June 12 to 21, so that there are only two years in which these records go beyond full bloom. In one of these there was considerable root storage; in the other, none. But there is abundant root storage at all stages before that period. Part of this may be called growth, rather than storage, but as recovery after cutting was prompt and normal on all of these plats, there must have been at least a considerable storage of reserves.

It might be anticipated that older stands would react in a different manner. We have only two years' results from stands more than 1 year old, but they strongly suggest a period of root accumulation in June after the full bloom stage, as reported by Graber, *et al.* However, the greatest accumulation from bud stage to early seed stage indicated by our data is only 38%.

At Columbus, however, there is no accumulation in the roots from full bloom to seed stage during the summer. Check samples were taken in the two-cutting plats in August during the full bloom stage, about a month before they were finally harvested. The averages of six comparisons in four different years, each yield an average of two samples, are as follows:

Stage of growth	Date of harvesting	Pounds per acre	
		Hay	Roots
Full bloom	Aug. 3–18	2,450	2,190
Seed stage	Aug. 28–Sept. 24	1,810	2,080

These figures show essentially no change, certainly no gain, in roots during that last month. It should be noted that at Columbus the leaves become unhealthy and drop off more or less before the seed stage is reached. These results, therefore, do not mean that a large root storage from full bloom to seed stage might not take in a region where the leaf surface remained healthy during that period. Indeed, even under our conditions there is a notable vigor of recovery after cutting at this stage which suggests that under more favorable conditions such a delay in cutting might be highly beneficial to the stand.

The most important single period of accumulation of root reserves is from the time of making the last cutting in the fall until freezing weather. This has been reported by Arny (1) for Minnesota. Our comparisons are summarized in Table 5.

TABLE 5.—*Fall storage in alfalfa roots.*

Year	Number of comparisons*	Pounds of roots per acre		
		Last cutting	Early November	Average gain
1925	4	2,340	2,550	210
1926	8	1,750	1,820	70
1927	6	1,770	2,410	640
1928	7	2,030	2,360	330
Average	25	1,920	2,230	310

*Each comparison in 1925 was between an average of four samples on each date, and in other years of two samples on each date. In the 25 comparisons only one failed to indicate a gain, and that was in 1926.

These data clearly indicate that there was an important period of storage in alfalfa roots in the late fall, although the plants did not in any instance reach the bloom stage before freezing weather. In 1925 and 1926 the last cutting was made September 23 and 25, thus leaving only a short time for accumulation, while in 1927 and 1928 the last cuttings were made September 15 and 11, respectively, thus allowing a longer period for storage in the two later years.

It has been customary for years to recommend that alfalfa go into the winter with a "good growth for winter protection." While the mulch effect of this top growth is undoubtedly of considerable importance, the writer feels that having a large healthy area of leaf surface available to put reserves into the roots during October is a more important reason for having the "good growth" so universally recognized as desirable.

These experiments do not show it, because they were not set up to show it, but from observations during these experiments the writer is convinced that the most important single factor in alfalfa management in the eastern part of the United States is the time of making the last cutting in the fall. Any experiment which compares different stages of harvesting alfalfa and does not make the last cuttings on the same date actually measures a composite effect, one component of which may directly oppose the other.

CHANGES IN ROOT RESERVES AFTER CUTTING

In 1925, 1926, and 1927 study was made of the changes in root reserves during recovery after cutting. In 1926 and 1927 duplicate square yard samples were harvested just two weeks after each cutting except the last. In 1925 the time was variable and somewhat longer. These results are summarized in Table 6.

This table shows a consistent loss in root reserves during the recovery after cutting. At the same time there is a slight, but distinct, loss in the percentage of nitrogen, showing that the protein reserves are drawn on to a somewhat greater extent than the other reserves.

There was also a consistent loss in the percentage of dry weight in the green roots during recovery after cutting, amounting to 4.9% in 23 comparisons.

TABLE 6.—*Losses in alfalfa roots after cutting*

Year	No. of comparisons*	Pounds of roots per acre			Percentage N in roots		
		At cutting	Two weeks later	Average loss	At cutting	Two weeks later	Average loss
1925......	8	1,717	1,520	197	2.18	1.91	0.27
1926....	15	1,501	1,376	125	2.09	1.91	0.18
1927.. ..	12	1,587	1,358	229	1.94	1.84	0.10
Final average.. .	35	1,580	1,403	177	2.06	1.89	0.17

*Of the 35 comparisons, only 5 failed to show a loss in weight of roots and only 6 a decrease in percentage of nitrogen.

FAVORABLE CONDITIONS FOR ROOT STORAGE

Clearly, a considerable area of healthy leaf surface is a prerequisite for root storage. Weather also plays a part in determining the amount of root reserves. It will require far more observations than we have available to make positive statements concerning the effects of weather on root storage, but it seems probable that dry weather is favorable to root storage. The writer has checked up on each period showing unusual accumulation during the four years' experiments, and in each instance the weather has been drier than normal. This observation agrees with other studies of root-top ratios.

RELATION OF VARIETY TO ROOT STORAGE

The 1926, 1927, and 1928 plats were made up of several varieties and strains of alfalfa, and in 1926 all of the averages reported included both common and variegated strains. A careful study of the yields of roots of individual plats affords no evidence that these two types of alfalfa behave differently as to the amount of root reserves stored. The average yield of 55 samples of common alfalfa roots was 1,525 pounds per acre and of the same number of similarly treated samples of Grimm and Hardigan alfalfa it was 1,545 pounds per acre. In 1927, three of the treatments afforded comparisons between Grimm and Kansas common. For the year, the average weight of 20 samples of roots from all cutting treatments was Kansas common 1,510 pounds, Grimm 1,574 pounds. The average number of plants per square yard for the same 20 comparisons was 89 for common and 117 for Grimm. While it is clear that Grimm, as usual, withstood the winter a little better than common, there was no suggestion that Grimm is more efficient than Kansas common in storing reserves in the roots.

EFFECT OF LEAFHOPPERS

Since root reserves have such a definite effect on the vigor and development of alfalfa, it may not be out of place to note that other factors may simulate or mask the effect of root reserves on development. The yellowing due to the work of the potato leafhopper has interfered with our experiments in many directions, and has been responsible for effects which might have been charged to root reserves. For example, when a strip around a large field is cut early and the main field cut later, the early-cut strip may be nearly killed by attacks of leafhoppers migrating to it from the main field. This has been attributed to deficient root reserves in the early-cut area, but the effect has been observed several times when lack of reserves could not have caused it. No disease problem seems more important in alfalfa culture in central Ohio than this "yellows" from leafhopper injury.

SUMMARY

1. Any extensive reduction of root reserves of alfalfa as measured by total weight of roots per acre consistently resulted in a reduction in yield and vigor of growth. Severe winterkilling from heaving followed extreme reduction in reserves, but the loss in vigor occurred without this.

2. Up to the first cutting for hay, young alfalfa gained in root reserves regularly and consistently, both in the fall of the seeding year and in late April, May, and early June of the next year.

3. Under Columbus conditions, alfalfa did not in four years show a gain in root reserves in August when the second cutting was allowed to stand from full bloom to seed stage. During the same period in June, gains took place in some years and not in others. This failure to store root reserves after full bloom was associated with yellowed and diseased leaves and does not indicate that gains during this stage would not take place in a region where the leaves remained healthy.

4. The loss in root reserves in recovery after cutting, as an average of 35 observations, was 177 pounds per acre. This was accompanied by an average loss in percentage of nitrogen (on an air-dry basis) of 0.17.

5. Recovery after cutting was almost uniformly accompanied by a decrease in the percentage of dry matter in the green roots, averaging 4.9% in 23 comparisons.

6. At Columbus the most uniformly important period of root storage is in October, when the last cutting of the season has been taken off early enough so that a considerable top growth has been produced by October 1.

7. The most favorable condition for storage of root reserves seems to be the combination of a large amount of healthy leaf area and drier weather than normal.

8. While Grimm and other variegated varieties of alfalfa are more winterhardy than common alfalfas under all cutting treatments, there is no evidence that this difference is due to or associated with differences in the amount of root reserves stored.

9. The effect of cutting on different dates at Columbus is determined nearly as much by the activities of the potato leafhopper as by root reserves, but at present the former are to a large extent unpredictable.

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EFFECT OF TIME OF CUTTING ON THE ELIMINATION OF BUSHES IN PASTURES[1]

B. A. Brown[2]

The fact that many potentially productive pastures have grown up to brush and wood land and the general interest in improving permanent pastures tend to make important any factors which will assist in reclaiming such land. For these reasons, it is deemed advisable to publish at this time a brief progress report on an experiment at the Storrs (Connecticut) Agricultural Experiment Station to measure the effects of time of cutting on the growth of bushes.

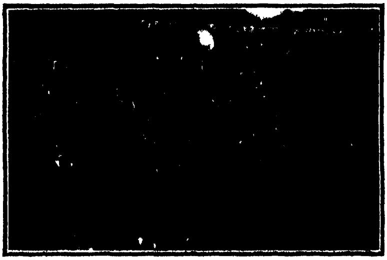

Fig. 1.—General view of brush plats mowed in May (left) and June for four years, 1925 to 1928. The stake with hat on it stands on the line between the two plats. (Photographed September 1929.)

Fig. 2.—General view of the brush plats mowed in July (left) and August for four years, 1925 to 1928. The stake with hat on it stands on the line between the two plats. (Photographed September 1929.)

The experiment in question was started in the early spring of 1925, when seven plats, each 40 by 150 feet, were laid out on some cut-over "sprout" land. This area had a stand of gray birch and soft maple trees, together with an undergrowth of alders, blueberries, and other bushes. In 1921, this stand was cut, and from then until 1925 nothing was done to retard the growth of the resulting sprouts. When the plats were laid out, the sprouts were from 3 to 7 feet high and from 0.5 to 1 inch in diameter.

In 1925, a different plat was mowed each month from April to September, inclusive, and one during the winter of 1925–26. The mowing was repeated at approximately the same time in 1926, 1927,

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[2] Associate Agronomist.

and 1928. In 1929, the surviving bushes were allowed to grow throughout the season. During this five-year period, the land was neither fertilized nor pastured. Thus, the date of mowing was the only varying factor.

After two cuttings, marked differences in vigor were shown by the bushes on the different plats. By not mowing the bushes during the growing season of 1929, these differences could be more easily seen and measured. Photographs were taken in September 1929 of the entire plats and of representative bushes growing on them. Figs. 1, 2, and 3 illustrate the general trend of the results.

Since the lengths of time from the 1928 cuttings to September 1929—when the pictures were taken—were not exactly the same for any two plats, the average size is not the best criterion by which to judge the effects of the different dates of mowing. The decreases in the area covered by bushes, weeds, and briars and the increases in the amounts of the desirable pasture species are more significant now. The plats mowed for four years in April and May were in September 1929 still largely covered by soft maples, alders, white (gray) birches, goldenrods, and blackberry briars, all over 30 inches high, and by the smaller growing species, ferns, cinquefoil, and blueberries. Very little space on these plats is occupied by palatable plants. Mowing during the winter gave practically the same results. The plat cut in September—the last month of the growing season in Connecticut—has a somewhat thinner stand of bushes and weeds than those mowed in April and May. On the other hand, the plats cut in June, July, or August present a greatly improved condition for pasture. On the whole, July seems to be the best time to mow so far as subduing the undesirable species is concerned. However, mowing in August and June gave results nearly as good. Figs. 1 and 2 show general views of the plats mown in May, June, July, and August.

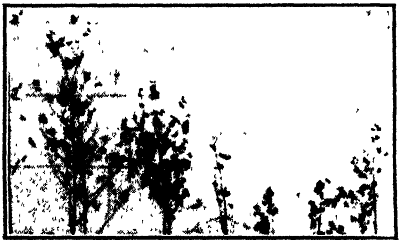

FIG. 3.—The effect of date of cutting for four years, 1925 to 1928, on the growth of gray birches (*Betula populifolia* Marsh) in 1929. From left to right: Mowed in April, May, June, July, August, and September. (Photographed September 1929.)

Somewhat similar results were obtained in Kansas by Aldous,[3] who tested the effects of date of mowing on buck brush and sumac. However, he found May 10 and June 10 to be the most effective dates of mowing. This is considerably before the best dates in Connecticut, but is probably due to the earlier season in Kansas. Aldous found that the most effective date of cutting was closely correlated with the time when the stems of the bushes contained the least amount of starch. To date, no analyses have been made of the bushes in the Connecticut experiments, but plans for the future include this feature.

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THE COMMERCIAL USE OF DOUBLE CROSSED CORN IN MINNESOTA[1]

H. K. Hayes[2]

The present method of corn breeding which has been universally adopted by experiment station workers is the result of intensive and extensive studies of the corn plant. The mode of attack was initiated about 1906 by East at the Connecticut Station and by Shull at Cold Spring Harbor. It consisted of the continued self-fertilization of individual plants within a line and a study of the biotypes which could be isolated by this means. After studying the field appearance of lines of corn which had been selfed for 6 years, a well-known botanist asked the author in 1912 if he thought it possible to continue inbreeding indefinitely without a continual loss of vigor in the inbred lines. This question emphasizes the changed viewpoint brought about by genetic studies.

Extensive studies of crosses of inbred lines have been made. F_1 crosses between inbred lines proved much more vigorous as a rule than the inbred lines and in some cases more vigorous than the normal variety from which the inbred lines were obtained. Shull in 1910 predicted that some method of hybridization would be used eventually by the producer of corn seed.

The large number of genotypically different inbred lines that could be obtained from a variety and the many and striking abnormalities which are present within inbred lines were recognized by all workers. This has led to extensive selection studies and to the general use of a terminology suggested by D. F. Jones known as "selection within self-fertilized lines." A description of the method by Jones was of great aid in creating a wide interest in this plan.

Even today the number of lines of corn which can be studied with the facilities available are less than are used for similar breeding experiments with other crops. In studies of wheat crosses at Minnesota for the production of stem rust resistant types, it is believed that from each cross which seems worthwhile an F_2 progeny of

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[2] Chief of Division of Agronomy and Plant Genetics. Acknowledgment is made to H. E. Brewbaker and F. R. Immer for their extensive aid in planning and conducting these studies.

10,000 plants is none too many and that during selection in the third to fifth generations, inclusive, approximately 1,000 progeny lines are desirable. Compared with this the number of selfed lines studied by the average experiment station corn breeder does not seem unduly large.

In 1925, ten of the corn belt experiment stations joined with the U. S. Dept. of Agriculture in a cooperative project on corn breeding under the provisions of the Purnell Act. The rather frequent association of workers has aided in further standardization of corn breeding methods. Early in the period of this cooperative study a somewhat factious question expressed a common doubt in the minds of many workers. Referring to the selfed lines, the question was, "Now that we've got 'em, what are we going to do with 'em?" That idea is still uppermost in the minds of many There is some doubt, also, regarding the desirability of the selfed lines available and various plans have been suggested for the production of improved lines.

A plan formulated by Richey and known as "convergent improvement" has as its aim the retention of all the desirable inherited characters of one selfed line and the addition to this of desirable genes from another line. If the plan will accomplish this, it seems superior to the more widely used method of breeding which consists of selection within the segregating generations after crossing two lines each of which contains some desirable characteristics not present in the other. A consideration of the possibilities of obtaining more satisfactory selfed lines is of major interest to the present-day corn breeder but that subject is without the scope of the present paper.

There are three methods of using selfed lines in an attempt to obtain more satisfactory corn. These are single crosses, double crosses, and synthetic varieties. No evidence is available of the production of an improved variety by the recombination of a number of selfed lines. This has been tried at Minnesota by the random recombination of 10 or more lines obtained from a variety, using the selfed lines which appeared to be the most vigorous available and were relatively uniform. The synthetic varieties yielded about the same as the normal corn from which they were obtained. The method appears logical and practical if some character such as resistance to a particular disease or earlier maturity is the chief characteristic desired.

Double crosses have appeared of greatest promise at Minnesota, although brief mention will be made of F_1 crosses in Golden Bantam which appear promising. A plan for an extensive test of the commercial utilization of double crosses will be given in some detail.

EXPERIMENTAL METHODS

In studies of the yielding ability of F_1 crosses to determine which lines to use in double crosses, the yield trials were made in two systematically distributed single-row plats of 12 hills each. The F_1 crosses were bordered by single rows of the normal open-pollinated corn from which the selfed lines were isolated.

Yield trials of double crosses and varieties were made in three-row plats, 17 hills long, the central row only being used for yield trials. Three to five systematically distributed plats were used.

For both the single and double crosses five seeds per hill have been sown in hills 3 feet, 6 inches apart and thinned to a three-plant basis. Two- and three-stalk hills surrounded on four sides by two- or three-stalk hills were used for the yield comparison.

The ear corn has been dried to a uniform moisture content and the yields computed on the basis of the number of bushels per acre of ear corn at 14% moisture.

The data presented for F_1 crosses and selfed lines of Golden Bantam sweet corn consist of results for only a single year. Single-row plats were bordered by normal Golden Bantam and three systematically distributed plats were used for each F_1 cross and two for the selfed line parents. Yield is given in percentage of normal on the basis of pounds of cut corn for canning.

EXPERIMENTAL RESULTS

Yields of the parental selfed lines used in the crosses are of interest. These lines were grown on the same field as the F_1 crosses and handled in a similar manner, except that they were bordered by plants grown from selfed seed.

Yields of the parental selfed cultures are given in Table 1. The lines used in the double crosses which will be increased for commercial distribution are placed in one group under the heading "used in double crosses." Lines tested in only single crosses will be summarized under the name of the variety from which they were

TABLE 1.—*Yield of selfed lines of corn in percentage of the yield of the normal variety.*

Source	Years selfed	Yielding ability in percentage of normal							
		15	30	45	60	75	90	105	120
Lines "used in double crosses"	8 to 13	3	3	1	–	–	–	–	–
Minn. No. 13	7 to 13	5	3	1	2	1	–	–	–
Rustler	7 to 9	2	1	1	1	–	–	–	–
N. W. Dent	7 to 11	–	4	–	1	2	–	–	–
Golden Bantam	6 to 7	–	–	–	1	4	1	–	1

obtained. The data for the lines used in double crosses were obtained in 1927. Data for 1929 only were available for the Golden Bantam selfed lines, while the remainder of the lines are on the basis of an average of results obtained in 1928 and 1929.

The Golden Bantam series of selfed lines yielded sufficiently well so that it appears practical to use F_1 crosses for commercial production providing the F_1 crosses in themselves are desirable. F_1 crosses of the seven inbred Golden Bantam lines given in Table 1 had been grown in observational trials in previous years. Several F_1 crosses were outstanding in previous trials. Yields for 1929 are given in Table 2.

TABLE 2.—*Yields of F_1 crosses between Golden Bantam lines selfed 6 to 7 years before the cross was made.*

Selfed line	77	78	81	82
72....	168	169	150	122
77 ...	—	152	—	—

The culture numbers of the inbred lines are given in a column at the left and in the row at the top of Table 2. The yield of the F_1 crosses are given in percentage of that of normal Golden Bantam. Thus, 72 x 77 yielded 168% as much as normal and all F_1 crosses proved much superior to normal in yield. Further studies are required with Golden Bantam to determine the consistency of yielding ability of these F_1 crosses. The data are given to emphasize the commercial possibilities of F_1 crosses when sufficiently satisfactory selfed lines can be obtained.

No F_1 crosses which appear commercially promising are available from selfed lines of field corn and the double crosses to be discussed later were obtained from F_1 crosses from selfed lines from different varieties. Rather extensive tests of all possible F_1 combinations between selfed lines of the same variety, however, are available. It is planned to study double crosses using selfed lines for a double cross which gives satisfactory yields in all possible single cross combinations. Yields of these F_1 crosses will be summarized in order to show the great promise of material now available and to indicate that high-yielding double crosses with uniform seed color can be obtained. These studies have been made with selfed lines of three varieties, *viz.*, Minn. No. 13, Rustler, and N. W. Dent (Table 1).

The yields of all possible single cross combinations are given in Table 3 for the selfed lines of Minn. No. 13 grown under culture Nos. 43, 46, 49, and 50 and for an average of the two years of 1928 and 1929.

TABLE 3.—*Yields of the six F_1 crosses of the selfed lines 43, 46, 49, and 50 in percentage of the yield of normal Minn. No. 13.*

Selfed line	46	49	50
43	120	138	116
46	—	117	119
49	—	—	119

The yields are in percentages of normal, the average of all six F_1 crosses being 121.5%. It seems logical to conclude that the double cross produced from these four lines (46 x 50) x (43 x 49) will at least yield as well as the average of the six F_1 crosses.

Average percentage yields for 1928 and 1929 of the six F_1 crosses obtained in each case from all possible single cross combinations of four lines of the same variety are given in Table 4. The yielding ability of the selfed lines in relation to normal corn has been given already (Table 1). The F_1 cross combinations grown in 1929 were those which, in the 1928 trials, appeared of greatest value.

TABLE 4.—*Average yields of six F_1 crosses from four selfed lines for the combination which will be tested as double crosses for the first time in 1930.*

	Yielding ability in percentage of normal				
Parental lines from	110	115	120	125	130
Minn. No. 13	1	–	5	–	–
Rustler	4	–	–	–	–
N. W. Dent	1	1	3	–	1

Each entry in Table 4 is an average of the yielding ability of the six possible F_1 crosses of four selfed lines. Five groups in Minn. No. 13 and four in N. W. Dent exceeded the normal variety by 20%. These data are given to indicate that double crosses of uniform seed color probably will be obtained which may be expected to yield even better than the double crosses which are available for distribution at the present time.

DOUBLE CROSSES WHICH IT IS PLANNED TO DISTRIBUTE

Three double crosses have been tested fairly extensively in central Minnesota and found sufficiently satisfactory to warrant increase for wider farm trials and distribution to farmers. The selfed lines used in these studies are as follows:

Selfed Line No.	Variety	Years selfed
11	Minn. No. 13	7
14	Minn. No. 13	13
15	Rustler	8
16	Rustler	8
19	Rustler	10
20	Rustler	9
21	N. W. Dent	9
22	N. W. Dent	9

These selfed lines have been combined in the following F_1 crosses: (11 x 14) = E, (16 x 20) = I, (15 x 19) = K, and (21 x 22) = L. The double crosses E x I, E x K, and E x L are the most promising of any that have been tested consecutively for three or more years.

Yields of Rustler, Minn. No. 13, N. W. Dent, and the double crosses E x I, E x K, and E x L are presented in Table 5. The yields are given in percentages of normal Rustler White Dent. Both Rustler and Minn. No. 13 have been selected at University Farm for a number of years. Seed for the following year's seed plat is selected from vigorous stalks in perfect-stand hills and only the very undesirable off-type ears are discarded.

TABLE 5.—*Average yields of three varieties and of the double crosses E x I, E x K, and E x L in percentage of Rustler.*

Variety	Univ. Farm 1926–29	Morris 1926–29	Goodhue Co. 1926–28	Chippewa Co. 1927–29	Meeker Co. 1928–29	Grand average
Rustler . .	100.0	100.0	100.0	100.0	100.0	100.0
Minn. No. 13	94.5	101.1	96.8	91.4	102.9	97.0
N. W. Dent.	86.7	91.1	—	—	—	—
E x I .	110.0	106.9	112.6	106.7	134.1	112.1
E x K..... .	108.6	110.0	104.1	103.6	123.0	109.0
E x L. ...	113.1	109.5	112.5*	97.3	118.8	109.7

*Two years only.

Rustler has been an outstanding variety at University Farm. It has yielded less than Minn. No. 13 at Morris, however, until the season of 1929, when it proved a high yielder in all trials. The double crosses have consistently proved superior to the normal varieties. Yielding ability was computed on the ear corn basis. A comparison of other characters is given in Table 6.

TABLE 6.—*Comparison of double crosses with normal varieties.**

Variety or cross	Percentage yield	Shelling percentage	Ears per stalk		Date silking	Percentage moisture at harvest
			Marketable	Nubbin		
Rustler	100.0	100.0	0.92	0.12	Aug. 2	36.8
Minn. No. 13 .	97.0	100.0	0.84	0.14	Aug. 2	35.1
E x I ...	112.1	101.5	0.99	0.08	July 29	31.7
E x K....	109.0	102.0	1.00	0.16	July 31	35.9
E x L....	109.7	101.4	1.05	0.11	July 30	30.5

*Average yield with Rustler as 100% (Univ. Farm, 1926–29; Morris, 1926–29; Goodhue Co., 1926-28; Chippewa Co., 1927-29; Meeker Co., 1928–29). Average shelling percentage (Univ. Farm; Goodhue Co., 1926; Chippewa Co., 1927–29; Meeker Co., 1928–29). Average number of marketable and nubbin ears per stalk (Univ. Farm, 1927–29; Morris, 1929). Average percentage moisture in corn at harvest (Univ. Farm, 1929; Morris, 1926–29; Goodhue Co., 1926–27; Chippewa Co., 1927–29; Meeker Co., 1928–29).

The double crosses exceeded Rustler and Minn. No. 13 in shelling percentage. On the basis of Rustler as 100, they averaged 1.4 to 2%

higher which should be added to the percentage yielding ability. The number of marketable and nubbin ears per stalk was computed from the 1927–29 data collected at University Farm. The crosses are somewhat superior in this respect.

The double crosses matured somewhat earlier than the normal varieties and a greater percentage of the ears were mature at time of husking than in the normal varieties. This is a very valuable characteristic in Minnesota. An increased yield, together with earlier maturity, means much more than a greater increase in yielding ability without an increase in earliness of maturity. Because of these desirable characters, it has been decided to increase for distribution double crosses E x I, E x K, and E x L.

PLANS FOR DISTRIBUTION

Many articles have appeared in the farm press extolling the value of hybrid corn. In some cases this has led farmers to cross two varieties and grow a hybrid mixture. Unadapted double crosses from neighboring states have been used in Minnesota. It is necessary, if double crosses are to be grown commercially, to teach the grower what hybrid corn consists of and how it must be produced and utilized. It seems that this can be accomplished to the best advantage by introducing these double crosses. Plans were made in 1929 for the first increase. Only a small quantity of seed of the selfed lines was available and this was increased by experiment station workers at University Farm.

After carefully considering the problem, it was decided to make the first crosses, E, I, K, and L, by hand pollination and at the same time to increase the stock of the inbred lines by sib pollination.

As only two small isolated plats were available, it was necessary to cover the ear shoots of each plant that was sib or cross pollinated, except in the case of plants growing in these two small isolated plats. For these plats all of one inbred line was detasseled. Cross or sib pollination was performed artificially even in these plats, although natural agencies may have been responsible for some pollination. An insect powder blower was used in making the pollinations. This work was handled by a graduate assistant who was paid at the rate of $125 per month and by boys who worked under his direction and were paid 25 cents per hour.

The amount of seed available for further increase in 1930 consists of approximately 132 pounds of the sib-pollinated material and 156 pounds of F_1 crossed seed, or a total of 288 pounds. Of this amount, approximately 64 pounds of seed were produced in the isolated plats.

The remainder was obtained from hand pollination. The actual cost of pollinating and harvesting the seed was about $185. In addition about $30 was paid for materials. The cost of the seed was a little less than $1.00 per pound and on this basis the cost of seed for the single crosses from which to make double crosses would be between $5 and $6 per acre. After actual test has been made it is hoped to use the plan suggested by Kiesselbach of combining each pair of selfed lines in a synthetic variety and crossing these two varieties for the production of commercial seed. The first trial of these crosses between F_2 combinations will be made in 1930. If this plan works satisfactorily with these crosses, it will reduce greatly the cost of seed production.

The double cross seed plat consisted of two rows of the cross to be detasseled to every one row which was used as a pollen parent. This method proved satisfactory and gave well-filled ears. Approximately 75 bushels of double crossed seed are available for wider farm trial in 1930.

The first increase in Minnesota of new and improved crop varieties is made by the experiment stations. The present plan for 1930 is to increase further the stocks of the sib-pollinated inbred lines and to make further F_1 crosses. Because of the limited seed available, it seems best to retain control of the inbred lines for at least another crop season.

According to the Minnesota plan, an experiment station committee decides in what counties to distribute this first increase and how much seed to place in each county. A county Crop Improvement Committee, consisting of three farmers, is appointed by the president of the Minnesota Crop Improvement Association. This committee, with the county agent and the extension agronomist, then selects approved growers who make further increase for wider distribution.

Seed is available for from 25 to 30 acres of hybrid plats from which to produce double cross seed corn this coming year. It is hoped to distribute this by the plan outlined above to 25 growers who may be interested in hybrid corn seed production. The seed produced would be registered by the Crop Improvement Association. The plan is to sell the seed of the single crosses to be used for hybrid seed production at the approximate price of $1.00 per pound which is about actual cost.

THE USE OF ADVANCED-GENERATION HYBRIDS AS PARENTS OF DOUBLE CROSS SEED CORN[1]

T. A. Kiesselbach[2]

It is rather generally agreed among students of corn improvement that the double cross is one of the most promising forms of recombination that may be employed in the immediate commercial application of the principle of selection within self-fertilized lines. It is the purpose of this paper to present data bearing upon a simplified manner of producing double cross seed. The new method under consideration differs from that now in use by way of substituting advanced-generation single crosses for first-generation single crosses as the parents of the F_1 double cross seed. Experimental results during three years indicate that this may provide a successful short-cut in commercial seed production and that it merits further trial.

While the designation "double cross" has come to apply to hybrids containing either 3 or 4 lines, this discussion is restricted to the orthodox double cross made by the mating of two single crosses. It would seem that the same general principles should apply in any multiple cross, regardless of the number of lines represented.

TWO METHODS CONTRASTED WITH RESPECT TO COMMERCIAL SEED PRODUCTION

PROCEDURE WHEN FIRST GENERATION HYBRIDS ARE USED AS PARENTS

The common method now in use involves the continual maintenance of four selfed lines as well as the two single crosses between them which serve as parental stock. In commercial seed production, the simplest plan with this method, after the selfed lines have once been established, calls for three isolated natural-crossing seed plats annually. Two of these are for production of the single cross seed and the third is for the production of the double cross seed. Fortunately, the selfed lines that are involved may be maintained incidentally in connection with the two natural crossing plats which produce the F_1 single-cross seed as follows:

By using 2-year-old seed for the male parent of a single cross and alternating in successive years the line to be used as the female parent, open-pollinated seed of the respective selfed lines is produced in the tassel-rows in alternate years. Numerous tests have shown that after an essentially homozygous constitution has been reached through selfing, such open-pollinated seed of selfed lines grown in isolation is essentially identical with that borne by self-fertilized plants.

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[2] Agronomist.

PROCEDURE WHEN ADVANCED-GENERATION HYBRIDS ARE USED AS PARENTS

When the two single crosses that are to serve as parents of the double cross seed have once been made, they may each be continued indefinitely under isolation as open-pollinated hybrids. They advance a generation each year in which grown, but their yield does not lower beyond that of the second generation hybrid which will normally average about two-thirds that of the corresponding F_1 hybrid. The maintenance of the parent hybrids and the production of the commercial double crossed seed can easily be accomplished by the use of a single seed plat annually. This involves carrying over a seed supply of opposite hybrid parents in alternate years, and presupposes that either hybrid may serve satisfactorily as the male or female parent. Seed produced by the male parent each year serves as the female parent in the following year. This is to be mated with 2-year old seed of the other hybrid parent. The basic selfed lines themselves need only be grown in occasional years to produce a new supply of uncontaminated single cross seed stock.

The natural crossing plats required annually in connection with both methods of producing F_1 double cross seed are indicated for a 6-year period in the following plan.

Suggested plan of natural crossing plats required during a 6-year period to produce commercial double cross seed by both the "first-generation-parent" and the "advanced-generation-parent" methods.

Year	F_1 single cross a x b or its reciprocal	F_1 single cross c x d or its reciprocal	F_1 double cross (a x b) x (c x d) or its equivalent
	F_1 Single Crosses Used as Parents		
	♀ ♂	♀ ♂	♀ ♂
1929	a x b	c x d	
1930	b x a	d x c	(a x b) F_1 x (c x d) F_1
1931	a x b	c x d	(b x a) F_1 x (d x c) F_1
1932	b x a	d x c	(a x b) F_1 x (c x d) F_1
1933	a x b	c x d	(b x a) F_1 x (d x c) F_1
1934	b x a	d x c	(a x b) F_1 x (c x d) F_1
	Advanced Single Crosses used as Parents		
1929	a x b	c x d	
1930	——	——	(a x b) F_1 x (c x d) F_1
1931	——	——	(c x d) F_2 x (a x b) F_1
1932	——	——	(a x b) F_2 x (c x d) F_2
1933	——	——	(c x d) F_3 x (a x b) F_2
1934	——	——	(a x b) F_3 x (c x d) F_3

TABLE 1.—*Comparative results with double crosses between first, second, and third generation single crosses, 1927.**

Generation of parents	No. of hybrids	Date in tassel	Height in inches		Per 100 plants				Shrinkage above 14%	Shelled corn	Shelled grain per acre	
			Ear	Stalk	Smutty	Barren	2-ear stalks	Suckers	%	%	Bushels	Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
					Hogue Hybrids							
F_1	5	7/27	29	79	3	1	1.0	4	2	86	55.2	100
F_2	5	7/28	31	77	5	2	0.4	1	1	85	55.0	100
					Hogue by White Prize Hybrids							
F_1	3	7/28	36	92	7	2	0.0	7	3	86	53.1	100
F_2	3	7/29	37	95	7	1	0.0	11	2	86	54.9	103
					Weighted Averages of Comparable Crosses							
F_1	8	7/27	33	84	5	1	0.6	5	2	86	54.4	100
F_2	8	7/29	34	84	6	2	0.3	5	1	85	54.9	101

*The individual yields obtained are classified in Table 2.

EXPERIMENTAL RESULTS

The most complete comparisons of the two methods of making double crosses were obtained in 1928 and 1929. Less extensive tests were made in 1927 and previously. The yield tests so far have been restricted to a comparison of double crosses between F_1, F_2, and F_3 single crosses. Theoretically, what applies to the use of F_2 and F_3 seed should be applicable for seed of later generations. Experimentaly, the seed has been produced by control pollinations made by the bagging method. The selfed lines employed have been inbred for 10 or more generations. The advanced-generation hybrid seed has been produced by sister breeding rather than inbreeding as this corresponds with mass production conditions. An effort has been made to produce five or more seed ears of each double-cross, each ear having been pollinated by a mixture of pollen from six plants picked at random. The seed ears of each cross were composited for the yield tests.

It was the general plan to grow in adjoining plats for direct comparison the corresponding combinations which differed only as to the generation of the parents. Although the individual hybrids were unreplicated, the principle of replication enters into the summary of results by averaging a comparatively large number of combinations. Prior to 1929 the plats consisted of one row 64 hills long. In 1929, three-row plats containing 60 hills were used. All of the corn was planted at a double rate and thinned by position to three plants per hill.

DOUBLE CROSSES BETWEEN F_1 AND F_2 HYBRIDS COMPARED

In the rather limited tests of 1927, eight double crosses between F_1 hybrids averaged 54.4 bushels per acre compared with 54.9 bushels when F_2 hybrid parents were used. There were no material differences with respect to vegetative characters, as shown in Table 1. The similar distribution of individual yields resulting from the two methods is evident in Table 2.

TABLE 2.—*Classification of individual yields of double crosses between F_1 and F_2 single crosses, 1927.**

	Bushels of shelled corn per acre					
Generation	45–48	49–52	53–56	57–60	61–64	Total
F_1	–	3	2	1	2	8
F_2	1	2	2	2	1	8

*The hybrids here considered are those summarized in Table 1.

TABLE 3.—*Comparative results with double crosses between first and second generation single crosses, 1928.**

Generation of parents	No. of hybrids	Date in tassel	Height in inches		Per 100 plants						Shelled grain per acre	
			Ear	Stalk	Smutty	Barren	2-ear stalks	Suckers	Shrinkage above 14% %	Shelled corn %	Bushels	Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
					Hogue Hybrids							
F_1	41	7/26	47.7	102	4	6	0.9	14	3	86	54.3	100
F_2	41	7/26	47.5	101	4	5	0.9	12	3	86	54.9	101
					White Prize Hybrids							
F_1	16	8/2	54.0	114	5	11	0.3	7	6	85	48.2	100
F_2	16	8/2	55.0	114	4	9	0.2	5	6	86	48.9	101
					Hogue by White Prize Hybrids							
F_1	7	7/30	48.0	105	3	4	0.1	5	6	85	56.1	100
F_2	7	7/30	49.0	105	3	4	0.3	5	6	84	56.1	100
					Weighted Average for all Combinations							
F_1	64	7/28	49.0	105	4	7	0.7	11	4	86	53.0	100
F_2	64	7/28	49.0	105	4	6	0.7	9	4	86	53.5	101

*The individual yields obtained are classified in Table 4.

The tests in 1928 included a total of 64 double cross combinations made both through crossing F_1 single crosses and F_2 single crosses. Comparing double crosses (Table 3) between F_2 hybrids with those between F_1 hybrids, the former yielded 1% more as an average for 41 Hogue Yellow Dent combinations and also for 16 White Prize combinations, while the average yields for 7 combinations between Hogue and White Prize single crosses were equal. A weighted average for the 64 combinations gives us yields of 53.0 bushels and 53.5 bushels, respectively, for double crosses between F_1 and F_2 single crosses. The difference is doubtless within the limits of experimental error and is not regarded as significant. No material differences were found with respect to various vegetative characters as summarized in Table 3.

A classification of the individual yields of these 64 combinations as given in Table 4 shows a very similar distribution for both methods.

TABLE 4.—*Classification of individual yields of double crosses between F_1 and F_2 single crosses, 1928.**

	Bushels of shelled corn per acre										
Generation	33–36	37–40	41–44	45–48	49–52	53–56	57–60	61–64	65–68	69–72	Total
			Hogue Yellow Dent								
F_1....		1	-	5	11	10	7	6	1	-	41
F_2....	–		1	5	11	6	11	7	–	–	41
			Nebraska White Prize								
F_1.....		3	2	5	2	1	2	1	–	-	16
F_2	2	2	2	1	3	2	2	–	2	–	16
			Hogue by White Prize								
F_1	–	–	1	-	1	1	2	1	1	–	7
F_2....	-	–	-	2	1	–	2	1	1	–	7
			All Combinations								
F_1	-	4	3	10	14	12	11	8	2	--	64
F_2	2	2	3	8	15	8	15	8	3	–	64

*The hybrids here considered are those summarized in Table 3.

In 1929, 41 double crosses (Tables 5 and 6) between F_1 hybrids averaged 57.9 bushels of shelled corn per acre compared with 57.6 bushels when corresponding F_2 hybrids were used as parents. No material differences in vegetative habits were found in relation to the generation of the parents.

As a straight average for the 3 years the use of F_1 and F_2 hybrids as parents resulted in double crosses which yielded 55.1 and 55.3 bushels per acre, respectively.

DOUBLE CROSSES BETWEEN F_1, F_2, AND F_3 HYBRIDS COMPARED

In the case of 12 combinations in 1928 we may compare the value of F_3 hybrids with that of F_2 and F_1 hybrids as parents of double crosses. These results are compiled in Tables 7 and 8. The relative yields

TABLE 5.—*Comparative results with double crosses between first and second generation single crosses (Hogue Yellow Dent), 1929.*

Generation of parents	No. of hybrids	Date in tassel	Height in inches		Smutty plants	Per 100 plants		Suckers	Shrinkage above 14%	Shelled corn	Shelled corn per acre	
			Ear	Stalk		Barren	2-ear stalks		%	%	Bushels	Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
F^1	41	7/23	36	82	3	4	1	8	4	86	57.9	100
F_2	41	7/23	36	82	3	4	1	9	4	86	57.6	99

secured from double crosses made from F_1, F_2, and F_3 parents, respectively, were 57.0, 57.1, and 57.4 bushels per acre. These are relative yields of 100, 100, and 101%.

In 1929, a similar comparison (Tables 9 and 10) was made for 10 double cross combinations. When F_1, F_2, and F_3 hybrids were used as parents, the double cross yields averaged, respectively, 57.9, 58.4, and 57.0 bushels of shelled corn per acre. These are relative yields of 100, 100, and 98%.

TABLE 6.—*Classification of individual yields of double crosses between F_1 and F_2 single crosses, 1929.**

Generation	Bushels of shelled corn per acre											Total
	33 36	37– 40	41– 44	45 48	49– 52	53– 56	57– 60	61– 64	65– 68	69– 72	73– 76	
F_1	–	1		3	8	7	5	10	3	4	–	41
F_2	–	1	1	2	5	10	9	4	4	4	1	41

*The hybrids here considered are those summarized in Table 5.

As a straight average for both years, the double crosses between F_1, F_2, and F_3 single crosses, respectively, yielded 57.5, 57.8, and 57.2 bushels per acre and were similar with respect to their vegetative development.

VARIABILITY OF DOUBLE CROSSES IN RELATION TO THE GENERATION OF THE PARENT HYBRIDS

In 1929, the coefficient of variation for three plant characters was calculated (Table 11) for the populations of 10 double cross combinations each of which was made by crossing F_1, F_2, and F_3 single crosses, respectively. In a weighted average of the 10 combinations with a total population of approximately 1,600, the mean coefficients of variation for plant height were 11.1 ± 0.139, 10.4 ± 0.128, and 10.7 ± 0.134, respectively, for double crosses between F_1, F_2, and F_3 single cross parents. Corresponding coefficients of variation for ear height were 15.1 ± 0.182, 15.1 ± 0.186, and 15.3 ± 0.184, while for number of days from planting to shedding of pollen the coefficients were 2.2 ± 0.028, 2.0 ± 0.026, and 2.2 ± 0.025.

Thus it appears that the generation of the parent hybrids does not materially affect the plant variability.

COMPARATIVE YIELDS IN THE NATURAL CROSSING PLAT WHEN ADVANCED-GENERATION SINGLE CROSSES ARE SUBSTITUTED FOR F_1 HYBRIDS

The possibility of substituting advanced generation hybrids for the standard F_1 hybrid parents in making double crosses raises the rather important question, What are the comparative yields of seed corn to

TABLE 7.—*Comparative results with double crosses between first, second, and third generation single crosses, 1928.**

Generation of parents	No. of hybrids	Date in tassel	Height in inches Ear	Height in inches Stalk	Smutty plants	Per 100 plants Barren	Per 100 plants 2-ear stalks	Suckers	Shrinkage above 14% %	Shelled corn %	Shelled grain per acre Bushels	Shelled grain per acre Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
					Hogue Hybrids							
F_1	9	7/25	48	98	5	7	0.4	22	3	85	56.1	100
F_2	9	7/25	47	98	4	6	0.4	17	3	85	55.4	99
F_3	9	7/25	48	98	5	6	1.0	14	3	86	57.1	102
					Hogue by White Prize Hybrids							
F_1	3	7/30	48	105	4	5	0	7	6	85	59.5	100
F_2	3	7/30	50	108	3	4	0	4	6	84	62.1	104
F_3	3	7/30	45	104	2	3	0	3	7	85	58.4	98
					Weighted Averages of Comparable Crosses							
F_1	12	7/26	48	100	5	7	0.3	18	4	85	57.0	100
F_2	12	7/26	48	101	4	6	0.3	13	4	85	57.1	100
F_3	12	7/26	47	99	4	5	0.1	11	4	85	57.4	101

*The individual yields obtained are classified in Table 8.

TABLE 8.—*Classification of individual yields of double crosses of F_1, F_2, and F_3 single crosses, 1928.**

Generation	45–48	49–52	53–56	57–60	61–64	65–68	69–72	Total
				Bushels of shelled corn per acre				
				Hogue Yellow Dent				
F_1	1	2	1	2	1	1	1	9
F_2	1	3	–	2	2	1	–	9
F_3	1	–	4	–	3	1	–	9
				Hogue by Nebr. White Prize				
F_1		–	1	1		1	–	3
F_2	–	–		2	-	1	–	3
F_3	–	–	1	1	1	–	–	3
				All combinations				
F_1	1	2	2	3	1	2	1	12
F_2	1	3	1	4	3	2	–	12
F_3	1	–	5	1	4	1	–	12

*The hybrids here considered are those summarized in Table 4.

be expected per acre by the two methods? Data secured on this point in 1927 and 1928 are reported in Tables 12 and 13. Comparable results for the selfed lines entering into the 21 single crosses reported are also included for 1928. In 1928, the second and third generation hybrids averaged, respectively, 68 and 66% as much grain yield as the first generation hybrids, while the selfed lines averaged 42% as much. In 1927, the second and third generation hybrids yielded 67 and 68% of the first. Repeated trials have indicated that the F_3 seed produced by composite sib-pollination may be expected to yield on a par with F_2 seed. There is no reason to suspect that advancing the seed to still later generations by this mass pollination method would materially alter its relative yield, provided no restrictive seed selection is practiced. If, as is commonly believed among corn workers, the best double crosses may be expected to average at least 15 to 20% better than the best commercial variety, then the seed plat which produces the commercial double cross seed by crossing advanced-generation parents should yield about 80% as much as the best commercial varieties.

If it were desirable to secure the maximum amount of double cross seed from the natural crossing plat, it should be entirely possible to use F_1 single cross seed for the female parent and advanced-generation single cross seed for the male parent. This would add somewhat to the complexity of seed production. Other modifications in the manner of combining first- with later-generation hybrids might prove feasible in special cases.

In the hands of careful corn growers the procedure herein reported would seem to be entirely practicable. Through it, with proper precautions, the hybrid seed stocks may be almost self-perpetuating

TABLE 9.—*Comparative results with double crosses between first, second, and third generation single crosses (Hogue Yellow Dent), 1929.*

Generation of parents	No. of hybrids	Date in tassel	Height in inches		Smutty plants	Per 100 plants		Suckers	Shrinkage above 14% %	Shelling %	Shelled corn per acre	
			Ear	Stalk		Barren	2-ear stalks				Bushels	Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
F_1	10	7/25	34	78	5	6	1	9	3	86	57.9	100
F_2	10	7/25	32	78	5	6	1	9	4	86	58.4	101
F_3	10	7/25	32	77	4	5	1	9	2	86	57.0	98

and the matter of seed production made more simple. Necessary provision must be made against contamination and for occasional replacement of seed stocks from basic sources. The necessity of thorough detasseling cannot be over-stressed where two hybrid seed stocks are to be continued for several generations by open pollination in a natural crossing plat.

TABLE 10.—*Classification of individual yields of double crosses of F_1, F_2, and F_3 single crosses, 1929.**

Generation	Bushels of shelled corn per acre											
	33-36	37-40	41-44	45-48	49-52	53-56	57-60	61-64	65-68	69-72	73-76	Total
F_1	–	1	–	–	2	2	-	2	2	1	–	10
F_2	–	1	–		1	2	2	2	–	1	1	10
F_3	–	1	–	–	3	2	1	–	1	1	1	10

*The hybrids here considered are those summarized in Table 9.

TABLE 11.—*Variability of plant characters in double cross corn hybrids which differ with respect to the generation of their hybrid parents; weighted averages for 10 combinations, 1929.**

Plant characters	Generation of single crosses used as parents		
	F_1	F_2	F_3
Height to first tassel branch, inches			
Mean	66.4±0.124	66.2±0.117	65.2±0.114
Coef. of variation	11.1±0.139	10.4±0.128	10.7±0.134
Height to ear, inches			
Mean	33.8±0.088	32.3±0.083	31.4±0.078
Coef. of variation	15.1±0.182	15.1±0.186	15.3±0.184
Days from planting to tasseling			
Mean	80.7±0.031	80.6±0.028	79.9±0.029
Coef. of variation	2.2±0.028	2.0±0.026	2.2±0.025

*Formula used for calculating variability is that given by Hayes and Garber in "Breeding Crop Plants", pp. 39-40. Total population used for various characters approximated 1,600 plants.

TABLE 12.—*Comparative results with selfed lines and F_1, F_2, and F_3 single crosses between them, 1928.*

Description	No. of hybrids	Date in tassel	Height in inches Ear	Height in inches Stalk	Smutty plants	Per 100 plants Barren	Per 100 plants 2-ear stalks	Suckers	Shrinkage of ear corn %	Shelling %	Yield per acre Bushels	Yield per acre Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Selfed	14*	8/6	33	79	4	12	5	2	7	80	24.0	42
F_1	21	7/28	43	96	7	8	1	10	4	85	57.0	100
F_2	21	7/31	41	88	3	9	1	5	6	85	38.4	68
F_3	21	7/31	42	90	3	8	1	6	6	86	37.8	66

*Results for selfed lines are weighted according to the number of times that each line enters into hybrid combination.

TABLE 13.—*Comparative results with F_1, F_2, and F_3 single crosses between selfed lines of Hogue Yellow Dent Corn, 1927.*

Description	No. of hybrids	Date in tassel	Height in inches Ear	Height in inches Stalk	Smutty plants	Per 100 plants Barren	Per 100 plants 2-ear stalks	Suckers	Shrinkage of ear corn %	Shelling %	Yield per acre Bushels	Yield per acre Relative
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
F_1	11	7/28	28	77	6	2	1	3	3	85	53.5	100
F_2	11	7/29	30	74	6	2	1	3	3	84	36.1	67
F_3	11	7/29	26	78	6	2	0	2	0	83	36.4	68

SAP EXTRACTION OF SORGHUM AND THE LOCALIZATION OF JUICE AND SUGARS IN INTERNODES OF THE PLANT[1]

GEO. JANSSEN, C. K. MCCLELLAND, AND W. H. METZGER[2]

The manufacture of sorghum syrup has grown to be an extensive industry among farmers living in regions which are capable of producing sorghum crops. Many farmers in the southern states have their own equipment for the manufacture of sorghum and cane syrup on a small scale. The syrup produced may be intended for their private consumption or it may be retailed locally. Many sorghum growers have become very efficient in producing a good grade of syrup.

The correct time of cutting sorghum plants for syrup has been obtained through practice. This practice, no doubt, has been guided by the extensive and detailed research conducted by the U. S. Dept. of Agriculture (2, 3, 4, 5),[3] and this may have helped to bring the sorghum syrup industry to its present-day significance.

With due regard to work previously reported, certain questions still arise as to the best manner of handling the sorghum plants previous to extracting the juice. For example, Is it advisable to strip the leaves previous to crushing and, if so, how long previous? This would apply both to the interval before cutting and before crushing. Furthermore, Is it advisable to cut the plants and allow them to lie in a pile any length of time before crushing? To answer some of these questions, the present investigation was undertaken and was planned so as to compare stripped with unstripped sorghum plants as follows: (a) Stripped and cut at time of crushing; (b) not stripped at time of crushing; (c) stripped and left standing certain periods before harvesting and crushing; and (d) stripped, cut, and left to lie various periods before crushing. Also, an effort was made to determine the sugar concentration of sap extracted from the various internodes of the plant and to determine the percentage of juice and its sugar concentration obtained by passing plants through crushers the rollers of which were set at different degrees of tension.

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[1] Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Arkansas. Submitted with the approval of the Dean of Agriculture as Research Paper No. 206, Journal Series, University of Arkansas. Received for publication January 10, 1930.

[2] Assistant Agronomists.

[3] Reference by number is to "Literature Cited," p. 638.

METHOD OF ANALYSES

The present investigation was conducted with the Honey variety of sorghum. From a 2-acre plat two rows of 132 feet each were stripped of their leaves and left standing in the field various periods of time before crushing, or else were cut down, placed in a pile, and let lie some time previous to crushing. The non-stripped stalks were treated likewise and as indicated in the tables. Thus, on October 9 (Table 2) analyses were made of sorghum plants that were stripped on October 1 and cut on October 4; not stripped but cut on October 4; stripped and not stripped on October 9, but cut on that date; stripped on October 1, cut October 9; stripped on September 25 and cut on September 25. Approximately 60 to 100 miscellaneous plants were crushed for each analysis.

The data on the localization of sugar in juice of the internodes of the plant were obtained from analyses made on the Honey variety. Approximately 100 internodes were used for these analyses. Each internode was cut separately and placed with its respective group before crushing.

Chemical analyses were made on the extracted juice for total sugars, starch, and dextrins. Ten cc of the juice were accurately measured out with a pipette and 150 cc of 95% alcohol were then added to precipitate any starch or dextrins present. After standing for 30 minutes, the starch or dextrins were removed by filtration, the filtrate was evaporated nearly to dryness at 65°C, taken up with water, clarified with lead acetate, hydrolized with 2.5% HCl at room temperature, and the reducing power of the total sugars determined as specified in the Munson and Walker methods (7). The amount of copper reduced was titrated by the Shaffer and Hartman (9) titration method. The percentage sugar was calculated in terms of glucose from the Munson and Walker tables (7).

The starch and dextrin precipitate on the filter paper was taken up with 2.5% HCl and hydrolized two hours under a reflux condenser. The reducing power was then determined as in the case of the total sugars.

The total sugars of the internodes (Table 2), based on dry weight, were determined as follows: Thirty of the 1, 2, 3, 6, 9, and 10 internodes were respectively reduced to one-half inch segments and one sample of 100 grams placed in boiling alcohol and another sample of 100 grams used for determining the dry weight. After decanting the alcohol, the sample was dried in the oven at 70°C. Fractional portions of alcohol and tissue equivalent to 1 gram dry weight were then used for analysis. The method of analysis used was similar to that described by Murneek (8).

RESULTS

The data pertaining to the percentage sugar in juice extracted from the various internodes of the sorghum plant are given in Table 1. The nodes have been designated as 1, 2, 3, 4, etc., internode 1 being the lower internode next to the soil, internode 2 the second internode from the ground, and so on. Internodes 9 and 10 are the internodes next to the sorghum head or panicle.

TABLE 1.—*Percentage juice and total sugars in juice of internodes of sorghum plants.*

Internodes No.	Weight of internodes, grams	Weight of juice, grams	Juice %	Juice to pulp ratio	Total sugars		Starch and dextrins		Grams of sugar in juice of 100 grams plant tissue
					Juice %	Pulp %	Juice %	Pulp %	
Analyzed Sept. 25, 1928									
1....	1,970	486	24.67	1:3.05	9.37	3.75	—	—	2.558
2.* . .	2,460	881	35.81	1:1.79	9.52	5.31	—	—	3.409
3 . .	2,725	1,143	41.94	1:1.38	9.90	7.18	—	—	4.152
4.... .	2,625	1,189	45.29	1:1.20	10.75	8.95	—	—	4.868
5....	2,450	1,127	46.00	1:1.17	11.40	9.75	—	—	6.840
6.... .	2,265	1,024	45.03	1:1.21	11.20	9.28	—	—	5.043
7.... .	2,145	863	40.23	1:1.48	10.15	6.85	—	—	4.083
8	1,975	853	43.18	1:1.31	9.53	7.28	—	—	4.115
9.	1,440	514	35.69	1:1.80	9.14	5.30	—	—	3.262
Analyzed Oct. 5, 1928									
1. ..	1,620	465	28.7	1:2.48	10.86	4.38	0.338	0.136	3.116
2	1,985	790	38.8	1:1.89	11.70	6.20	0.246	0.131	4.539
3 .	2,000	865	43.2	1:1.31	12.39	9.48	0.246	0.187	5.352
4 . ..	2,010	850	42.3	1:1.36	12.50	9.20	0.236	0.174	5.287
5. ...	1,900	888	46.7	1:1.13	12.80	11.33	0.302	0.267	5.977
6	1,590	735	46.2	1:1.16	13.11	11.30	0.320	0.276	6.056
7 .	1,150	535	46.6	1:1.14	12.56	11.00	0.326	0.286	5.852
8 .	1,070	500	46.7	1:1.14	12.50	10.94	0.416	0.365	5.837
9......	1,030	462	44.7	1:1.22	12.45	10.20	0.422	0.346	5.565
10....	600	215	35.8	1:1.79	11.69	6.53	0.390	0.218	4.185
Analyzed Oct. 23, 1928									
1........	870	205.7	23.6	1:3.22	8.46	2.62	0.247	0.076	1.996
2	1,000	314.5	31.5	1:2.17	10.06	4.89	0.292	0.134	3.168
3.. ...	980	350.7	35.8	1:1.79	10.18	5.69	0.256	0.144	3.644
4	940	314.5	33.5	1:1.98	10.18	5.11	0.208	0.105	3.410
5 . ..	910	309.9	34.1	1:1.93	10.06	5.20	0.289	0.150	3.430
6	780	305.4	39.2	1:1.56	10.42	5.69	0.328	0.210	4.084
7...... .	670	228.4	34.1	1:1.93	10.30	5.32	0.286	0.148	3.512
8	530	151.4	28.6	1:2.56	9.26	3.61	0.247	0.096	2.648
9.......	420	110.6	26.3	1:2.79	9.00	3.22	0.331	0.119	2.367
10 . . .	400	88.0	22.0	1:3.54	8.04	2.27	0.347	0.098	1.768

TABLE 2.—*Total sugars and dextrins in internodes calculated on dry weight, analyzed Oct. 23, 1928.*

Internode No.	Sugars %	Dextrins %	Starch %	Hemicellulose %
1	43.3	0.89	1.27	10.55
2............	41.9	1.20	1.82	10.85
5....	40.5	1.36	3.98	10.85
6........	46.0	1.27	5.77	12.35
9............	34.3	1.27	2.89	12.05
10............	35.1	1.51	2.59	11.60

The data on the percentage of juice expressed by ordinary cane crushers are shown graphically in Fig. 1, and the percentage sugars in Fig. 2. From Fig. 1 it will be seen that the maximum amount of juice as well as the greatest percentage of sugar is extracted from the middle internodes of the plant.

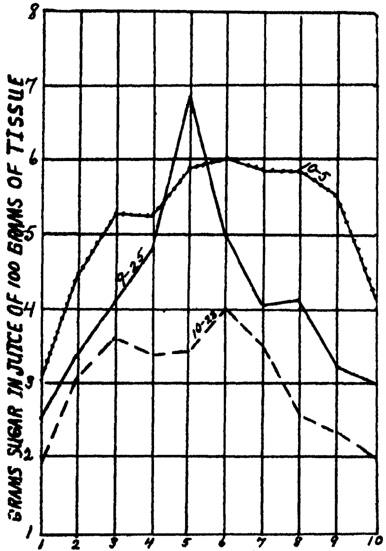

FIG. 1.—Sugar distribution in juice of the internodes of sorghum plants obtained by passing the internodes through a cane crusher.

In order to determine whether there were differences in the sugar content of the various internodes of the plant based on dry weight, the percentage of sugar was determined in the plant tissue of the various internodes. These data are given in Table 2. From this table it will be noted that the basal and middle internodes of the plant have a greater sugar concentration than the top internodes. However, the difference in the percentage of sugar between the base and middle internodes is not as great as between the top and middle internodes. It is also apparent that the middle internodes of the plant are higher in starch content than the upper and basal internodes.

Table 3 contains data on the sugar concentration of plants given different treatments previous to crushing. These data are shown graphically in Figs 3, 4, and 5. The data on the percentage of juice obtained from plants given various treatments previous to crushing are given in Fig. 3. From these data it will be seen that the largest percentage of juice was obtained from plants

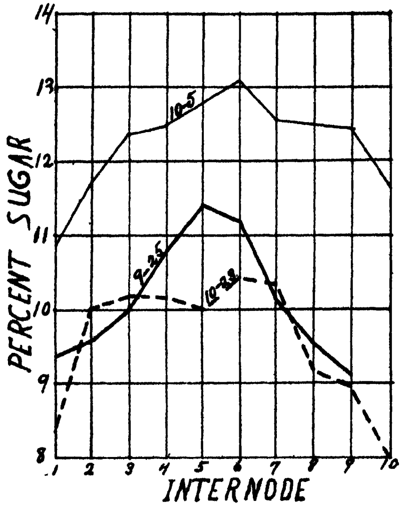

FIG. 2.—Percentage sugar in juice extracted from internodes of sorghum plants.

that were stripped on October 1, but were not cut for crushing until the day of crushing. If this is compared with plants which were not stripped but which retained their leaves, it will be seen that the latter produced a much lower percentage of juice than the former.

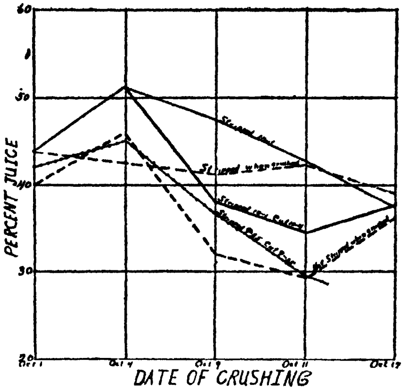

FIG. 3.—Percentage juice extracted from sorghum plants which were subjected to different treatments. Unless otherwise stated, cut when crushed.

Fig. 4 shows the concentration of total sugar of plants which were given different treatments. From this it will be seen that plants which were stripped on October 1 and cut on date of analysis contained less sugar than any of the other treatments. If Figs. 3 and 4 are compared, it will be noted that there is a converse relationship, namely, wherever large percentages of juice were obtained the percentage of sugar was lower than where small quantities of juice were expressed. This seems to be significant.

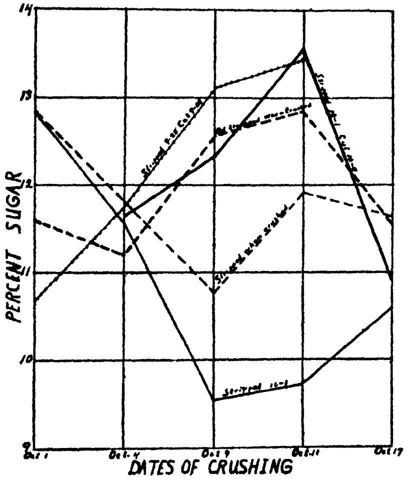

FIG. 4.—Percentage total sugars in juice expressed from sorghum plants which were given different treatments previous to time of extraction. Unless otherwise stated, cut when crushed.

Fig. 5 gives a comparison of the grams of sugar produced from sap of 100 grams of sorghum plant tissue of different treatments previous to the time of crushing. From this graph it will be noted that the plants which were stripped on October 1 and cut at date of crushing on October 1 and 4, with the exception of the treatment cut and stripped October 1 and crushed on October 4, contain the largest amount of sugar per 100 grams of plant tissue. The excessive amount produced in the treatment cut October 1, stripped October 1, and crushed October 4 cannot be explained unless some of the starch was hydro-

TABLE 3.—*The percentage total sugars in juice of sorghum plants which were given various treatments previous to crushing.*

Sample No.	Cut	Stripped	Weight of cane, grams	Weight of juice, grams	Juice %	Juice to pulp ratio	Total sugars Based on juice* %	Total sugars Based on pulp† %	Starch and dextrins Based on juice* %	Starch and dextrins Based on pulp† %	Sugar in juice of 100 grams of tissue, grams
					Crushed and Analyzed, Oct. 1						
1	Oct. 1	Not	5,810	2,356.8	40.0	1:1.465	11.60	7.95	0.272	0.186	4.64
2	Oct. 1	Oct. 1	4,010	1,760.75	43.9	1:1.275	12.82	10.05	0.470	0.370	5.61
3	Sept. 25	Sept. 25	4,140	1,770.6	42.7	1:1.340	10.67	7.97	0.202	0.150	4.55
					Crushed and Analyzed, Oct. 4						
1	Oct. 1	Not	2,790	1,433.0	51.3	1:0.946	11.45	12.20	0.218	0.232	5.90
2	Oct. 1	Oct. 1	2,780	1,475.0	53.0	1:0.880	12.14	13.80	0.178	0.202	6.58
4	Oct. 4	Oct. 1	2,800	1,340.0	45.0	1:0.945	11.75	10.86	0.218	0.202	5.29
5	Oct. 4	Not	2,830	1,300.0	45.8	1:1.170	11.22	9.60	0.254	0.217	5.13
6	Sept. 25	Sept. 25	2,840	1,460.0	51.3	1:1.080	11.64	12.36	0.202	0.215	5.97
					Crushed and Analyzed, Oct. 9						
5b	Oct. 9	Not	2,520	806.3	32.0	1:2.120	12.56	5.92	0.172	0.081	4.02
5a	Oct. 4	Not	2,785	992.0	35.6	1:1.807	13.84	7.69	0.134	0.074	4.24
6a	Oct. 9	Oct. 1	2,775	1,327.3	47.8	1:1.090	9.54	8.75	0.308	0.380	4.48
7	Oct. 9	Oct. 9	2,780	1,141.6	41.1	1:1.435	10.78	7.54	0.150	0.105	4.46
6b	Oct. 4	Oct. 1	2,795	1,073.6	38.4	1:1.603	12.30	7.68	0.172	0.107	4.68
4	Sept. 25	Sept. 25	2,800	1,028.3	36.7	1:1.722	13.14	7.64	0.150	0.087	4.82
					Crushed and Analyzed, Oct. 11						
6a	Oct. 11	Oct. 1	2,720	1,164.2	42.8	1:1.336	9.74	7.29	0.030	0.022	4.28
6b	Oct. 4	Oct. 1	2,760	955.9	34.6	1:1.880	13.58	7.22	0.116	0.061	4.69
5b	Oct. 11	Not	2,680	792.7	29.6	1:2.380	12.86	5.408	0.134	0.056	3.81
5a	Oct. 4	Not	2,630	969.4	36.9	1:1.712	11.36	6.64	0.091	0.053	4.21
7	Oct. 11	Oct. 11	2,700	1,146.1	42.4	1:1.355	11.90	8.78	0.228	0.169	5.02
4	Sept. 25	Sept. 25	2,320	693.1	29.9	1:2.340	13.40	5.73	0.472	0.215	4.10
					Crushed and Analyzed, Oct. 17						
6a	Oct. 17	Oct. 1	2,780	1,032.9	37.2	1:1.711	10.58	5.94	0.322	0.187	3.93
6b	Oct. 4	Oct. 1	2,700	1,023.8	37.9	1:1.635	10.90	6.66	0.145	0.088	4.13
5b	Oct. 17	Not	2,850	1,037.3	36.4	1:1.750	11.54	6.59	0.322	0.184	4.22
5a	Oct. 4	Not	2,790	915.0	32.8	1:2.050	13.90	5.56	0.316	0.124	4.56
7	Oct. 17	Oct. 17	2,870	1,123.4	39.1	1:1.555	11.64	7.48	0.238	0.153	4.54

*Calculated on basis of juice. †Calculated on basis of pulp lized to sugar while the stalks laid in the pile. Similar increases in sugar content of the October 4 crushing over October 1 of the latter treatment, namely, by allowing plants to lie in a pile a few days after cutting, may be noted by comparing the treatment stripped September 25, cut September 25, and crushed on October 1 and 4. It appears that in these cases hydrolysis of starch to sugar may have taken place. It must be noted that the total amount of sugars in all treatments are relatively high in results from October 4 crushing. This was partially due to the increased amount of juice obtained at this sampling For the other three crushing dates, namely, October 9, 11, and 17, the amount of sugar produced from plants stripped and cut September 25 is somewhat lower than from plants given other treatments, such as stripped at date of crushing; stripped October 1, but cut October 4; and stripped October 1, but cut at date of crushing. The sorghum plants which were not stripped before crushing do not compare in amounts of sugar produced with plants that were stripped. This seems to be very specific It would appear from these data, with the exception where plants were cut and left lie in a pile a few days previous to crushing, that sorghum plants should be stripped at time of crushing or possibly a day or so before crushing in order to obtain the maximum amount of sugars from a given quantity of tissue. This latter point must be substantiated further.

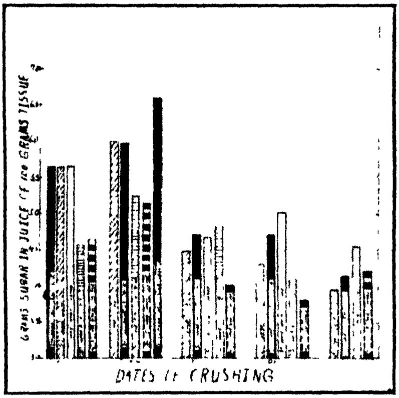

FIG. 5.– Showing grams of total sugar in juice of 100 sorghum stalks given different treatments previous to time of extraction. Unless otherwise stated, cut when crushed.

EFFECT OF RECRUSHING AND TIGHTNESS OF ROLLERS

The data on the effect of the tightness of sorghum crusher rollers on the percentage of juice and sugars obtained are given in Table 4. The extraction data in the table were obtained by using three separate samples of sorghum and subjecting one sample to light pressure, the second to a medium pressure, and the third to a heavy pressure. The data on repeated crushings were obtained by using one sample of sorghum tissue and subjecting it first to a light pressure, then to a medium pressure, and lastly to a heavy pressure.

TABLE 4.—*The effect of various pressures applied to crusher rollers on the percentage juice and sugars extracted from sorghum plants in the process of sorghum crushing.*

Date analyzed	Tightness of rollers	Weight of cane. grams	Weight of juice, grams	Juice %	Juice to pulp ratio	Total sugars based on Juice %	Total sugars based on Pulp %	Starch and dextrins based on Juice %	Starch and dextrins based on Pulp %	Sugars in juice of 100 grams of tissue, grams
				Single Extractions						
Oct. 30, 1928	Loose	2,780	645.1	23.20	1:3.14	8.86	2.82	0.229	0.073	2.05
	Medium	2,790	917.3	32.90	1:2.41	11.02	4.65	0.698	0.289	3.62
	Tight	2,880	1,247.6	43.30	1:1.20	10.12	8.40	0.274	0.227	4.38
Nov. 2, 1928	Loose	3,020	407.7	13.50	1:6.22	8.92	1.43	0.182	0.029	1.20
	Medium	2,890	1,345.4	46.55	1:1.13	8.46	6.36	0.191	0.111	3.93
	Tight	2,860	1,730.5	60.51	1:0.65	12.62	19.45	0.271	0.413	7.63
				Repeated Crushings						
Oct. 30, 1928	Loose	9,630	2,434.5	25.30	1:2.91	10.66	3.66	0.229	0.788	2.69
	Medium	7,080	2,103.8	21.80	1:2.15	11.08	5.50	0.423	0.195	2.41
	Tight	4,540	1,292.9	13.50	1:2.51	10.36	4.13	0.385	0.153	1.39
Nov. 2, 1928	Loose	9,220	2,568.5	27.86	1:2.53	9.80	3.88	0.214	0.084	2.73
	Medium	6,495	2,545.9	27.61	1:1.51	9.60	6.19	0.325	0.215	2.45
	Tight	3,865	1,046.4	11.31	1:2.47	10.42	4.22	0.415	0.168	1.13

Relative to the extraction data in Table 4 where the samples were subjected to different pressures, it will be noted that for the October 30 analysis the greatest percentage of sugar was obtained from juice extracted from stalks subjected to a medium pressure, but the greatest percentage of juice was obtained when the heavy pressure was applied. However, the second analysis, on November 2, shows the greatest percentage of sugar as well as juice extracted from stalks subjected to the heavy pressure. In both cases the amount of sugar per 100 cc of juice was greatest in juice extracted with the greatest pressure.

The second part of Table 4 shows that when the same sample is subjected first to light, then to medium, and later to heavy pressure, the percentage juice obtained from the stalks decreased with each successive crushing, but that as high as 11% was obtained from the last crushing. The percentage of sugar in the juice obtained from the various crushings remained about the same, never varying over 1%. These figures vary somewhat from the extraction data given in the table where separate samples were subjected to the various pressures. It will be noted that in this case the percentage sugar in the sap did increase with increased pressure. The difference can only be accounted for by the different methods used in the sap extraction. The results from both methods of extraction show that the pressure rollers should be as tight as possible so as to remove the maximum amount of juice from the stalks.

DISCUSSION

A study of correct time of cutting sorghum plants is not a part of the present investigation. This subject has been well developed by Collier (4, pages 414, 502, 505) and the fundamental principle, as shown by him, remains the same. It will be merely noted here that the amount of sugars produced from the juice of 100 grams of tissue first increases and then decreases (Fig. 5) as the season advances. From this graph it would appear that about October 4, under Arkansas conditions and with the Honey variety, was the best date for making sap extractions based on the total amount of sugar present per unit weight of tissue. The amount and percentage of sugar present, no doubt, would be somewhat dependent upon the amount of juice obtained per unit of tissue. Comparing Fig. 3 with Fig. 4, it will be noted that, in general, high sugars are related to low juice percentages and vice versa. The percentage juice extracted from the plant, other things being equal, depends on the amount of moisture in the soil (Collier, page 458). Collier's data show that the percentage of juice obtained from sorghum stalks bears an inverse ratio to the sugar content of the juice. This latter fact is corroborated in the present investigation.

It has already been pointed out that the stripped sorghum plants produced a larger percentage of juice than the unstripped plants. On the other hand, it will be noted that the percentage sugar obtained from the juice of the two types of plant was in favor of the unstripped plants. This may have been due to an added sugar content resulting from carbon assimilation of the leaves or to loss of juice by evaporation from the leaves, leaving the juice more concentrated in sugars. These results vary from those of Collier (4, pages 101, 1879) who found that stripping sorghum plants resulted in a decreased amount of juice, together with a decrease in percentage of syrup produced. These percentages, however, were based on the green weight of the plant, including the leaves. In the present analyses the percentage was figured on the green weight minus the leaves.

Bryan (1, page 33) found that the percentage of reducing sugar was greater for the unstripped cane, but that the percentage sucrose was greater for the stripped cane. He suggested (page 10) that allowing the leaves to remain on the plant may cause a loss of juice due to reabsorption. He also suggests that unless the leaves are removed from the plant the clarification of the juice and syrup obtained from them would be difficult.

It will be noted that in the case of sorghum plants cut on September 25 and October 4 and allowed to lie in piles the total sugars increased. This may have been due to two reasons, first, conversion of starch and dextrins through hydrolysis to sugars, and second, evaporation of juice, making the sap more concentrated. In both cases it will be noted that the percentage juice (Fig. 3) was materially reduced over those plants which were crushed on the day of cutting.

From the results given here it would appear that the best method of harvesting would be to strip the plant at time of crushing or allow it to lie in a pile in a stripped condition a day or so before crushing. This may do two things. First, it may hydrolyze some of the starch and dextrins over to sugar, and second, it may tend to make the juice more acid, thereby carrying some of the sucrose over to glucose and thus preventing it from crystalizing out after the syrup is made.

The localization of juice in the sorghum plant has caused some discussion among sorghum growers. It is the usual practice to remove the grain of the sorghum previous to crushing the stalks. The amount of stalk to remove along with the head is a matter of controversy. It was partially to decide this question that sugar analyses were made of each separate internode of the sorghum plant. Figs. 1 and 2 give the percentage of juice and amount of sugar obtained from the juice of 100 grams of sorghum tissue. It is quite evident from these figures that the percentage of juice and the amount of sugar obtained per unit of tissue are greatest for the fourth to eighth internodes or the middle internodes. It is evident, therefore, that a portion of the upper part of the stem may be left attached to the head on its removal and yet not seriously reduce the yield of sugar. A similar suggestion may be made for the base internodes. The analyses for total sugars in the internodes of the sorghum plant based on the dry weight of the tissue show (Table 2) that the upper portion of the plant is much lower in sugars than the middle and lower portions. It is also evident that the basal portions are not greatly at variance with the middle portion of the stem. The data in Table 2 would indicate that some of the sugar in the basal internodes is not as completely removed in sap extraction as in the middle and upper internodes of the stem. This might be explained partially on the basis of the greater toughness of the lower internodes which therefore might resist complete extraction.

These results are not greatly at variance with those quoted by Hensel (6) who suggests that the upper stalks contain little sugar but do contain many impurities, and therefore 12 to 18 inches of stalk should be left attached to the head on its removal. He states, however, that the stalks should be cut as close to the ground as possible since the lower portion is rich in sugars. This also agrees with the results reported here. It is noted, however, that the juice extraction is not complete and also the percentage of sugars in the juice is not as great as for juice extracted from the middle internodes. Basing the analyses on the total sugar in the tissue, however, little difference is noted (Table 2). Collier (3, page 63), basing his conclusions on the results of many analyses, states that, "It appears there exists no marked difference in the amount of juice present in the upper and lower halves of the canes, nor in the quality of this juice, as indicated by either the relative specific gravities or the total amount of solid matter present in the juice." From the analysis of sugar cane Collier (4, page 463) shows that the butt portion of cane plants (based on four analyses) contains 15.36%, the middle portion 12.95%, and the top portion 3.21% of sucrose. Collier stated further that these results differ from the sorghum plants where the top and basal portions yield about alike in respect to the quantity of sugar.

From the results obtained above, as well as from the data obtained by other workers, it is quite evident that a portion of the upper stalk may be removed with the head and not seriously decrease the sugar yield of the plant.

SUMMARY

1. The percentage juice and the total sugars of juice extracted from sorghum plants in the process of crushing for syrup manufacture were determined on plants given the following treatments: (a) Cut without stripping leaves at time of crushing; (b) cut with stripping leaves at time of crushing; (c) stripped, cut, and left to lie in a pile for various intervals before crushing; and (d) unstripped and left lie in piles before crushing.
2. It is clearly shown that there is a proper time for harvesting sorghum in order to obtain high percentage of juice and of total sugar (Fig. 5). The highest total sugar was obtained from October 1 and October 4 cuttings; less from the September 25 cutting and later dates in October.
3. There is some difference in the value of internodes from different parts of the sorghum stalks, the central having the highest, the lower ones an intermediate, and the uppermost the least value (Fig. 2 and Table 1).
4. Heavy pressure during the processes of crushing the sorghum stalks usually gave the higher amounts of sugar and juice (Table 3).
5. By repeating the crushings three times and by increasing the pressure of the rollers in each case, the respective crushings yielded total sugars in ratio of 2.71:2.4:1.26, or in percentage, approximately 43:40:17.
6. Stripping of leaves from the plant three to four days previous to cutting and crushing caused a slight depression in amounts of total sugars obtained on various dates (Table 2).
7. Allowing the stalks to remain in piles several days after cutting increased the sugar content of the juice probably due to two reasons, namely, evaporation, thereby making the sap more concentrated; and hydrolyses of starch and dextrins to sugars.
8. Allowing leaves to remain on stalks in each instance reduced the percentage of juice and the total amount of sugars (Table 2).

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INDICATIONS THAT AVAILABLE NITROGEN MAY BE A LIMITING FACTOR IN HARD WINTER WHEAT PRODUCTION[1]

P. L. GAINEY AND M. C. SEWELL[2]

The presence of small, well-defined areas, usually 2 to 4 feet in diameter, of taller and darker green plants in grain fields in the central and eastern states is a common observation in early spring. Similar conditions have been reported from the Pacific Coast. In Kansas such a spotted condition is very striking in wheat fields, even in western sections of the state where there is limited rainfall.

Under Kansas conditions the pasturing of winter wheat seems to be especially conducive to the appearance of such spots, and since solid manure is without effect on the current crop if dropped subsequent to planting, they may logically be attributed to deposits of urine. In many instances, however, their origin can be definitely traced to other conditions.

The dark green color and vigorous growth always observed in such areas suggests the possibility that available nitrogen may play an important rôle. Their repeated appearance upon soil of high potential fertility, together with the wide-spread opinion that nitrogen is not a limiting factor in wheat production in this region, would militate against such an explanation.

However, in efforts to secure information from as many different angles as possible in general nitrogen studies of western Kansas soils, it was felt that a study of the possible relationship, if any, of nitrogen to such spots was worthy of investigation.

Accordingly, samples of growing grain and soil were collected from typical spots and the immediately adjacent surrounding area in 38 wheat fields in 20 counties of central and western Kansas. Two samples of soil were taken, one for chemical and one for bacteriological study. The former was heavily treated with toluol to stop bacterial activity and was analyzed for NO_3 and total nitrogen. Duplicate samples of the latter were raised to the optimum moisture content for nitrification, incubated six weeks at room temperature, and again analyzed for NO_3.

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[1] A preliminary report offered as contribution No. 190 from the Department of Agronomy and No. 124 from the Department of Bacteriology, Kansas Agricultural College, Manhattan, Kans. Received for publication January 13, 1930.

[2] Professor of Bacteriology and Associate Professor of Soils, respectively.

A summary of the data obtained in the form of averages for the 38 comparisons is recorded below.

Source of material	N in soil %	N in plants %	NO_3 in fresh soil, p.p.m.	NO_3 in incubated soil, p.p.m.	Height of plant, inches	Weight of plants, grams
General field	0.132	1.425	20.2	157.5	8.4	0.89
Spots.......	0.143	2.630	52.4	517.6	17.1	2.32
No. times spot values exceeded field values.....	34	38	35	35	38	36

These data show that plants from the spots had made 2.6 times the total growth, contained 1.8 times as much nitrogen per unit weight, and had actually assimilated 4.68 times as much nitrogen per plant as those from the field at large. Notwithstanding this assimilation by the plants, the soil of the spots contained 2.5 times as much NO_3 and was capable of increasing this surplus to 3.3 times as much in six weeks. Furthermore, the data were almost invariably of the same qualitative order.

Apparently, the soil from the spots, either because of the quantity or quality of its nitrogen content or because of the activity of its flora, was capable of furnishing a much larger quantity of available nitrogen than was the general field soil.

A comparison of the total nitrogen values shows that on the average that of the spots was slightly higher. The differences, however, are not believed to be sufficient to account for all the differences in NO_3 accumulation. Certainly in many instances there was no deficiency of total nitrogen in the surrounding soil. Furthermore, in those comparisons where the nitrogen content of the spot was less than the adjacent soil, the accumulation of NO_3 in the former was invariably higher than in the latter.

Such experiments as have been conducted in an effort to determine the relative activities of the microflora, independent of the soil's nitrogen content, have been inconclusive. In some instances soil from the spots apparently contained a more active nitrifying flora, while in other instances the reverse was true.

A comparison of the phosphorus content of plants from 11 selected fields gave as an average 0.283 and 0.269%, respectively, for plants from the general field and from spots. These values indicate that phosphorus was not a determining factor.

Circumstances would not permit of the comparison of yields in the 38 fields previously mentioned, and in lieu thereof yields were taken from spots and adjacent plants in 22 fields in the vicinity of Manhattan. The ripe grain was harvested from the same four drill rows for a distance of 2 feet in a spot and from a similar distance immediately adjacent thereto, such areas approximating 1/10,000 acre. The average weight of grain in grams was 44 1 and 127.5, respectively, for the general field and for the spots.

A surplus of available nitrogen is sometimes considered to be the cause of weakening the straw, thereby predisposing to lodging. A comparison of the breaking strength of straw from the 22 harvested areas, however, invariably revealed stronger straw from the spots, the average increased resistance to breaking being 37.5%.

As a summary, it is believed these data may be tentatively interpreted as indicating that the increased growth and yield of grain on the type of spots under study can be attributed primarily to a more abundant supply of available nitrogen: and that the soil is able to supply more available nitrogen to the growing plant because a limited quantity of nitrogen capable of being more easily transformed into the nitrate form has found its way into the soil. Extensive experiments are now under way that, it is believed, will definitely determine whether this interpretation is correct

THE SPONTANEOUS CULTURE METHOD FOR STUDYING THE NON-SYMBIOTIC NITROGEN-FIXING BACTERIA OF SOILS[1]

R. H. WALKER, J. L. SULLIVAN, AND G. G. POHLMAN[2]

Since the discovery of the aerobic, non-symbiotic, nitrogen-fixing bacteria, their importance in relation to permanent soil fertility has been repeatedly emphasized. Appreciable amounts of nitrogen from the atmosphere may be added annually to soils in good chemical and physical condition when these organisms are present. A number of investigators have shown, however, that many soils do not contain these organisms and in such cases other means of maintaining and increasing the nitrogen supply must be resorted to.

In order to study the occurrence and activities of this group of organisms, many methods have been devised. Unfortunately, according to most of these methods the organisms are placed under artificial conditions which are entirely different from those prevailing in their natural habitat. The results obtained by the use of these methods have often led to erroneous conclusions. In order to overcome this difficulty, Winogradsky (2, 3, 4)[3] has developed the "spontaneous culture" method. This method involves two separate procedures, namely, the growth of the organisms in the soil itself and on silica gel. In the soil plate procedure, starch is mixed with soil at the rate of 5 grams per 100 grams of soil and sufficient water is added to make a thick paste. The soil is then packed into halves of petri dishes and the surface is smoothed by means of a moistened glass slide. After 2 to 5 days incubation at 28° to 30° C, colonies of nitrogen-fixing bacteria develop on the surface of the soil. These are quite similar to the colonies formed on agar plates, and it is possible to obtain almost pure cultures of Azotobacter by making transfers from these colonies.

In order to test soils for lime and phosphorus deficiencies, Winogradsky added small amounts of these materials to the soils with the starch in the tests. When these materials induced a more vigorous growth of the nitrogen-fixing bacteria, he concluded that the soils were lacking in these constituents and would probably respond to fertilization. He also suggested that this test might serve to indicate other soil deficiencies, such as a lack of organic matter, available potassium, sulfur, etc.

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[1] Contribution from the Department of Soils, Iowa State College, Ames, Iowa. Received for publication January 18, 1930. The authors take pleasure in acknowledging their indebtedness to Dr. P. E. Brown for his helpful suggestions in carrying out the work and in the preparation of the manuscript.

[2] Assistant Chief in Soil Bacteriology and Research Fellows, respectively.

[3] Reference by number is to "Literature Cited," p. 648.

In the silica gel plate procedure, a nitrogen-free nutrient solution containing mannite is added to silica gel in large petri dishes 20 cm in diameter. After the excess water is evaporated from the plates, they are inoculated by sprinkling 1 gram of soil uniformly over the surface of the gel. The plates are then incubated at about 30°C for 5 to 7 days. These cultures serve two purposes. They not only permit the study of the occurrence of the organisms in the soils, but also of their activities, by measuring the increase in the nitrogen content of the incubated plates. According to Winogradsky, the combination of these two procedures, the use of soil plates and silica gel plates, gives a very complete picture of both the occurrence and activities of this group of bacteria.

In our studies on the occurrence and activities of the nitrogen-fixing bacteria in variously treated soils, we have used the spontaneous culture method, including both the soil plate and silica gel plate procedures, slightly modified from those developed by Winogradsky. A series of plats at the agronomy farm of the Iowa Agricultural Experiment Station were chosen for this study, as they were known to support a fairly vigorous growth of Azotobacter. This series has been cropped to corn continuously since 1913 and the plats have received the following fertilizer treatments·

Plat 905—Check—No treatment
Plat 906—Farm manure applied at the rate of 8 tons per acre, once every four years.
Plat 907—Farm manure and lime. The manure applied as on plat 906, and ground limestone in amounts sufficient to neutralize the acidity as indicated by lime requirement tests once every four years.
Plat 908—Lime applied as required according to lime requirement tests, once every four years.
Plat 909—Check—No treatment.

Most of the soil on this series of plats is classed as Carrington loam. The soil of plat 909, however, contains more sand, and part of it should be classed as Carrington fine sandy loam.

The H-ion concentration of the soils from these plats was determined at the time of sampling. The results are presented in Table 1.

TABLE 1.—*The H-ion concentration of soils from continuous corn plats.*

Plat No.	905	906	907	908	909
pH............	5.60	5.98	7.11	6.23	5.57

SOIL PLATE PROCEDURE

Samples of fresh soil were taken from each of the plats and brought to the laboratory for testing. Three 100-gram samples of each soil were weighed out and treated as follows: (a) Potato starch (5%), check; (b) starch + lime (0.4%); and (c) starch + lime + di-sodium phosphate (0.6%).

After the materials were thoroughly mixed with the soil, sufficient water was added to make a thick paste. The moistened soil was then packed into duplicate halves of petri dishes and the surface was smoothed by means of a moist spatula. The plates were then placed in moist chamber culture dishes and incubated at 28°C.

After 3 days incubation a slight Azotobacter growth was apparent on the soil from plat 907 which had received applications of lime and manure in the field. The other soils showed no visible growth at that time. After 4 days the number of Azotobacter colonies had increased considerably on the soil from plat 907 and a few colonies had developed on the soils from plats 906 and 908. At the end of 5 days incubation the Azotobacter development was very definite and pronounced on some of the soils, while on others there was no visible Azotobacter growth. The results have been tabulated and are presented in Table 2.

In the case of soil from plat 905, there was a good growth of Azotobacter on the plates where lime and phosphate were added to the soil in the test, a few small colonies occurred where lime alone was added, and none were found on the plates receiving starch without lime or phosphate. There was some mold growth on the plates where no lime was used. This was also true in most cases for the other soils. There was very little mold growth on any of the plates receiving lime.

With soil from plat 906 which had been manured in the field there was some Azotobacter growth on the plates of soil treated with lime and phosphate, but not as much as there was on the corresponding plates made from soil from plat 905. There was no Azotobacter growth on the plates in which the soil was treated with starch and lime.

The best growth of Azotobacter was secured with the soil from plat 907. The plates in which the soil was treated with starch alone showed a good growth, but the colonies were slower to develop than where the lime and phosphate were added. On the plates of these latter soils there was more Azotobacter growth than on the plates from any of the other soils and the colony development was also much earlier. The colonies were larger and more hyaline than on the plates where no phosphate was added to the soil.

TABLE 2.—*The development of spontaneous cultures of nitrogen-fixing bacteria on soils from continuous corn plats after 5 days incubation at 28°C.*

Plat No. and treatment	Check plates (starch only)	Plates receiving starch + lime	Plates receiving starch + lime + phosphate
905, check	No Azotobacter growth, a few mold colonies	A few colonies of Azotobacter on one plate and none on the other, growth not so vigorous as on soil treated with lime and phosphorus	A good development of colonies on both plates, colonies large and vigorous, as good as on soil from plat 907 with lime and phosphorus but slower to develop
906, manure	No Azotobacter colonies, but a few molds	A few colonies on one plate and none on the other, colonies slow to develop and small	A few colonies on each plate, earlier development than on the lime-treated soils, larger and more vigorous
907, manure + lime	Good Azotobacter growth, but slower in developing than on plates with lime and phosphorus	Good growth on one plate, while only a few colonies on the other; colonies smaller than on lime and phosphorus plates and slower to develop	Excellent colony development, best of any plates, developed sooner, were larger, more hyaline, and whitish in color; no molds
908, lime	A few colonies on each plate, slow to develop and small	A few colonies on each plate, slow to develop and small	More colonies developed than on the plates not receiving phosphate, were larger, earlier to develop, and more vigorous
909, check	No Azotobacter colonies, numerous molds	No Azotobacter colonies, no molds	Small mold colonies beginning to develop, no Azotobacter

The excellent growth of Azotobacter on the plates from soil from plat 907 may be attributed to the fact that this soil had received applications of manure and lime in the field. These treatments undoubtedly made conditions more nearly optimum for the growth of Azotobacter than in the other plats where lime or manure alone had been applied or where no fertilizer had been used. It is very significant that even in this soil which had been fertilized with manure and lime, the growth of the Azotobacter was stimulated considerably by further applications of lime and phosphorus in the laboratory. This seems to indicate that this soil is still deficient in lime or phosphorus or in both for the maximum growth of Azotobacter, although the pH was 7.11.

With the soil from plat 908, there was a very slight growth of Azotobacter on the plates of soil which received only starch, but a much larger growth was secured by the addition of lime and phosphate.

With soil from plat 909 there was no growth of Azotobacter on any of the plates, even where lime and phosphate were added. On the check plates of this soil there was considerable mold growth, but on the plates of soil treated with lime there was none, and where lime and phosphate had been added together only a few small colonies occurred.

The character of the growth of the non-symbiotic nitrogen-fixing bacteria as described above is shown in Fig. 1.

A number of points seem to be quite definitely indicated from this test. First, it was shown very clearly that the soil treated with lime and manure in the field supported a much more vigorous growth of Azotobacter than the soils treated with either lime or manure alone and the Azotobacter growth on the latter soils was more vigorous than in the soils receiving no fertilization. In fact, according to this test, no active Azotobacter organisms were found in one of the check soils. The results show further that the growth of the Azotobacter in these soils was stimulated considerably by the addition of lime and phosphate to the soils in the plate tests. This was true in all soils that contained the organisms.

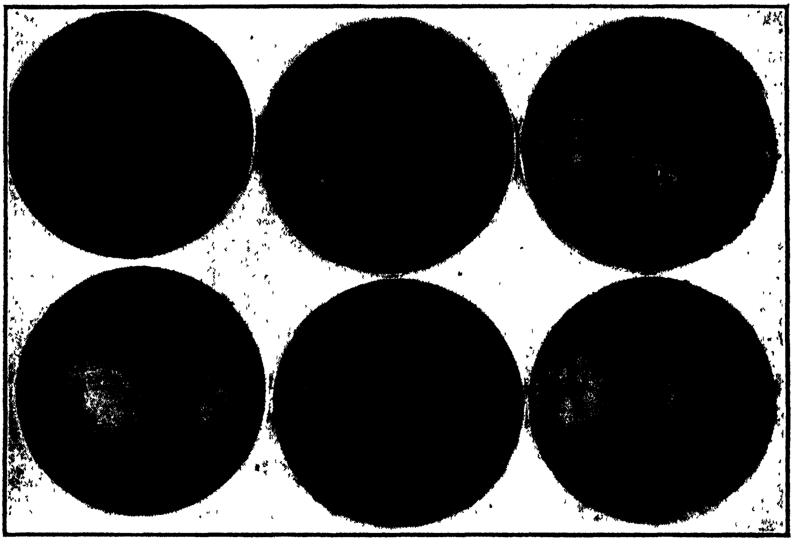

FIG. 1.—The character of growth of the non-symbiotic nitrogen-fixing bacteria on the surface of a soil in spontaneous culture tests. Plat 907, manure and lime. From left to right, check; lime; lime and phosphate.

SILICA GEL PLATE PROCEDURE

In this phase of the work silica gel plates were prepared as directed by Fred and Waksman (1), except that potassium silicate was used instead of a mixture of sodium and potassium silicates. The plates were then inoculated by spreading 1 gram of fresh soil uniformly over the surface of the silica gel. The soils used for inoculation were taken from the same series of plats as those studied by the soil plate procedure. After inoculation the plates were incubated at 28° to 30°C for 7 days.

On the plates inoculated with soil from plats 905, 906, 907, and 908, clear, slimy colonies began to appear after 1 or 2 days. As growth continued, the colonies spread until the entire surface was almost completely covered with the thick slimy mass. This material gradually turned brown and was very characteristic of typical Azotobacter growth. On the plates inoculated with soil from plat 909 there was no colony formation characteristic of the nitrogen-fixing bacteria. These results agree very well with those secured in the soil plate procedure. Soils from plats 905, 906, 907, and 908 were shown to contain Azotobacter by both tests, while no Azotobacter growth was secured when soil 909 was used in either test.

At the end of the incubation period, the silica gel plate cultures were tested for total nitrogen. The difference in nitrogen content between the control plates, whose nitrogen content had been determined immediately after inoculation, and the incubated plates was taken as the amount of nitrogen fixed by the micro-organisms which developed on the plates. The amounts of nitrogen fixed by the organisms while growing on these plates are given in Table 3.

TABLE 3.—*The nitrogen fixed on silica gel plates when inoculated with soils from the continuous corn plats in mgm of nitrogen.*

Plat No.	Plate 1	Plate 2	Average
905	11.280	12.670	11.975
906	10.155	14.125	12.140
907	11.140	10.970	11.055
908	10.030	11.120	10.575
909	0.780	0.310	0.545

These results show that appreciable amounts of nitrogen were fixed on the plates having the typical Azotobacter growth, while only a negligible amount was fixed on the plates where no typical growth appeared. The amounts of nitrogen fixed in the cultures containing Azotobacter are quite similar for all plats and it is probable that similar amounts of nitrogen would have been fixed on the cultures from soil from plat 909 if there had been any aerobic nitrogen-fixing organisms in this soil.

This point was demonstrated in another experiment. An acid soil increased in nitrogen content by only 0.55 mgm when tested for its nitrogen-fixing power by the silica gel plate procedure. After the same soil had been inoculated with a pure culture of Azotobacter and allowed to stand a few days, 10.035 mgm of nitrogen were fixed in a similar test. This would seem to indicate that the soil contained no aerobic nitrogen-fixing organisms, or that if there were any present, their physiological efficiency had been lowered to the point where they were unable to fix nitrogen. When this same soil was tested by the soil plate procedure, no colonies characteristic of this group of organisms appeared. The results obtained from using the two procedures would then seem to justify the conclusion that this particular soil contained none of the aerobic, non-symbiotic, nitrogen-fixing bacteria. If the colonies had developed on the soil plates and had fixed only small amounts of nitrogen on the silica gel plates, it probably would have been correct to assume that the organisms had lost their ability to fix nitrogen as a result of growing in a soil that was not suited for their best development.

By using the two procedures simultaneously in testing soils it appears quite probable that accurate information may be obtained regarding both the occurrence and activities of the aerobic, non-symbiotic, nitrogen-fixing bacteria of soils. In addition, it is entirely possible that its use may be extended to the study of soil deficiencies, such as a lack of lime, phosphorus, and other necessary food constituents.

This method certainly has many advantages as it is simple in manipulation, it requires only a comparatively short time to obtain results, and most important of all, it permits of the study of the nitrogen-fixing bacteria in their natural habitat and under practically the same environmental conditions to which they are accustomed in the soil in the field.

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FRACTIONAL NEUTRALIZATION OF SOIL ACIDITY FOR THE ESTABLISHMENT OF CLOVER[1]

WM. A. ALBRECHT AND E. M. POIROT[2]

Various tests for soil acidity and lime requirement of soils carry the general presumption that the soil must be neutral for successful growth of the clover crops. In consequence, the amount of limestone recommended is that amount of calcium carbonate revealed by the particular test as necessary to neutralize completely 2 million pounds of soil, or an acre 7 inches. If the application of limestone to a 7-inch layer of the root zone suffices to establish clovers, the questions logically follow, Might not this treated area be reduced to a much shallower stratum? or, Is it necessary to have other than certain limited, limed areas accessible to the plant roots? Previous reports (1, 2, 3, 5, 6)[3] suggest this possibility, so that the work here described was undertaken in order to answer these questions more fully.

PLAN OF EXPERIMENT

Clovers were seeded on a sour soil, beginning in 1927, which were treated with varying small amounts of finely ground limestone applied directly with the seed and comparing the crop with that obtained on the same soil treated with the more common 10-mesh agricultural limestone at the rate of 2½ tons per acre, or the amount considered as the "lime requirement" of this particular soil. In all trials, the application of the 10-mesh limestone was broadcast from 6 months to a year in advance of the seeding of the clover. The work was always done on a field basis, and in some trials as extensively as 30 acres, on soil which had never been limed or seeded to clover.

The fine limestone of the first trial consisted of 200-mesh material, but 30-mesh stone was later substituted for this. The fineness of the latter, according to standard sieve analysis, is given in Table 1 along with similar data for the 10-mesh stone. It is to be noted from the table that 66.7% of the 30-mesh stone was fine enough to pass the 100-mesh sieve, while this degree of fineness was obtained in only 39% of the 10-mesh stone.

The soil used is known as Gerald silt loam. The surface is a friable, brownish-gray, silt loam about 10 inches deep, underlain by an impervious plastic, brown, clay subsoil grading into a gravelly or

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[1] Contribution from the Department of Soils, University of Missouri, Columbia, Missouri. Received for publication January 18, 1930.

[2] Associate Professor and graduate student, respectively.

[3] Reference by number is to "Literature Cited," p. 657.

TABLE 1.—*Sieve analyses of 30-mesh and 10-mesh limestone.*

Sieve size	10-mesh stone %	30-mesh stone %
On 10-mesh	14	—
On 20-mesh	17	trace
On 40-mesh	15	0.4
On 60-mesh	8	11.8
On 80-mesh	4	11.0
On 100-mesh	3	10.0
Through 100-mesh	39	66.7

silty clay material at a depth of about 3 feet. Its topography is so flat that surface drainage is poor. It constitutes a large part of the original prairie area of southwestern Missouri the native vegetation of which was mainly bluestem and other common prairie grasses. No significant acreage of cultivated legumes is grown in this area. This soil type is very sour according to the Truog test, gives a densely red or blood-colored solution with the thiocyanate test, and has a pH of 5.5 for the surface 7 inches. Common experience has placed its lime need at 2½ to 3 tons per acre of 10-mesh limestone for clover growth. It is low in fertility and contains, according to analysis, but 2,370 pounds of nitrogen and 1,120 pounds of phosphorus per 2 million pounds of surface soil. The soil used in these trials had been cropped for over 40 years in a system of extensive grain farming and represents a low degree of fertility.

EXPERIMENTAL RESULTS

FIRST YEAR

In early March (1927) a mixture of 10 pounds of inoculated sweet clover and 4 pounds of inoculated red clover were drilled on 1 acre of wheat fertilized with 200 pounds of superphosphate the preceding fall. By means of a single-disc drill with fertilizer attachment the seed was put into the soil in direct contact with 200-mesh limestone used at the rate of 700 pounds on this area. The resulting stand of mixed clovers was excellent and the growth of the sweet clover during the summer reached a height of about 2 feet. A part of this acre was allowed to remain for the next year (1928) and produced good growth of both the sweet and the red clover. Though no weights of yields were taken, the growth was almost equal to that on the adjoining field given manure and 2½ tons of 10-mesh limestone a year in advance of and commercial fertilizer along with the clover seeding. Difficulty was experienced, however, in applying the 200-mesh limestone through the fertilizer attachment of the drill, as it failed to feed through the delivery machinery without constant attention.

SECOND YEAR

Mechanical difficulties in distributing the extremely fine limestone (200-mesh) necessitated the use of less finely ground stone. Consequently, a 30-mesh limestone was employed in subsequent work. The trials which started in March 1928 were arranged to test the effectiveness of inoculation as well as that of different amounts of lime The treatments used are listed in Table 2. Calcium in the soluble form as calcium chloride was used in connection with the inoculation to learn whether this might be of value in helping the crop. The seed mixture and method of lime application were the same as the preceding trial and were put on fertilized winter wheat in March while the soil was moist and even sticky in some places. This soil condition facilitated deeper penetration by the disc drill and effected a better cover of the seed.

TABLE 2.—*Amounts of limestone and methods of inoculation used in second trial.*

Plat No.	Amount of limestone in pounds per acre 30-mesh	 10-mesh	Method of inoculation
1	100	——	100 pounds soil
2	200	——	———
3	——	——	200 pounds soil
4	300	——	Cultures*
5	300	——	Cultures†
6	300	——	200 pounds soil
7	500	——	Cultures*
8	500	——	Cultures†
9	500	——	200 pounds soil
10	500	——	Cultures‡
11	——	——	Cultures‡
12	500	——	200 pounds soil§
13	——	5,000	Cultures†

*Commercial cultures were applied in triple the amount of that commonly used.

†Commercial cultures of common dosage.

‡A 10% calcium chloride solution was applied to the seed after it had been inoculated with the common dosage of commercial cultures.

§This soil was treated with 10% calcium chloride solution.

A uniform stand resulted in good growth until May when a shortage of rain occurred, amounting to only 0.09 inch, for this month. By the middle of May the result of the lack of moisture became quite evident and the young clover began to wilt and die in all plats except those treated with both lime and soil inoculation. Death of the entire stand occurred on the plats receiving calcium chloride on the seed but no lime and on the unlimed plat inoculated by soil only. About 25% of the stand remained where triple dosage of cultures was used, while 50% remained under normal dosage of cultures. Where the 5,000 pounds of 10-mesh limestone and cultures were used, the stand became very irregular, with areas of good clover and some of complete failure in consequence of the May drought. This comparative relationship between the plats persisted during the rest of the year, except in the case of the plat receiving 500 pounds of lime and 200 pounds of soil, where the stand seemed to be reduced in the late summer.

The spring growth on these plats during the next year of this 1928 trial emphasized the same differences as of the previous year. No significant quantities of sweet clover plants ever developed on the plats, possibly because of defective seed, and all yield data given represent red clover. The hay yield on the plat receiving 300 pounds of fine limestone and 200 pounds of soil was 3,600 pounds per acre, while 3,000 pounds were harvested where 5,000 pounds of 10-mesh limestone were used. The spring conditions of these two plats were similar, as shown by Fig. 1. The seed yield as the second crop of this year again showed the same relative difference for these two plats.

FIG. 1.—Spring condition of clover on soil with 300 pounds of 30-mesh limestone (above) and 5,000 pounds of 10-mesh limestone (below). The check strip is visible on the lower right.

Even though the stand had thinned out on the plat receiving 500 pounds of fine lime, it gave yields of hay and seed intermediate to the above two plats. The yields of the seed crop on the other plats were too small to permit accurate recovery.

THIRD YEAR

During the third year (1929) the experiments included two 30-acre fields and five 1-acre plats. These trials were designed to observe the results, on a more extensive scale, of the most promising of the previous treatments, and to test whether the use of 300 pounds of fine limestone as a guarantee for red clover would permit of improvement by supplementing it with fertilizer and different methods of inoculation. For the first purpose, a mixture of 30-mesh limestone and soil in the ratio of 2.1 was drilled on a 30-acre field in early April at the rate of 450 pounds per acre in direct contact with a mixture of 8 pounds of sweet and 6 pounds of red clover seed. This applied 300 pounds of limestone per acre. Part of this field was drilled when the soil was rather wet, another part when it was dry and compact, while on a third part the seeding followed after the crust had been broken by the rotary hoe.

For the sake of comparison, use was made of an adjoining field of equal area which had been given 2½ tons of 10-mesh limestone in advance of the wheat seeding the previous fall. This field was seeded with the same clover mixture increased by 4 pounds of sweet clover. In addition to the limestone, part of this field had also been given manure as a winter top dressing on the wheat. The date of the clover seeding on the field of 10-mesh limestone was about 5 weeks in advance of that seeded with the fine lime. The wheat on each of these 30-acre fields was put in after soybeans and was given 175 pounds of 2–12–4 fertilizer. For the second purpose, namely, to test possible improvements in the use of the fine limestone and soil mixture, 1-acre plats were used with the various treatments given in Table 3.

TABLE 3.—*Limestone, fertilizer, and inoculation treatments used on 1-acre plats of the third trial.*

Plat No.	Lime in pounds	Fertilizer in pounds	Inoculation
1	300	————	100 pounds soil
2	293	————	7 pounds inoculated limestone*
3	300	Nitrophoska, 25	100 pounds soil
4	300	Ammonium sulfate, 20 Superphosphate, 40	100 pounds soil
5	293	Ammonium sulfate, 20 Superphosphate, 40	7 pounds inoculated limestone

*Solutions of artificial cultures were mixed with small quantities of the finely powdered limestone.

At 7 weeks after seeding, the small sweet clover plants on the 30-acre field given the 10-mesh limestone appeared yellow and revealed no nodules on the roots as shown in Fig. 2. In contrast, however, the small red clover plants were inoculated profusely. As a possible help to the sweet clover which seemed doomed apparently because of lack of inoculation, this field was given inoculated soil at the rate of 200 pounds per acre broadcast with an endgate limespreader. In about 10 days, nodules were found on the plantlets and at a later time improvements in the crop condition were evident, so that a stand of sweet clover within the red clover resulted. Counts of the nodules on the plants were made at the time of this special inoculation treatment and also on the plants from the field given the fine limestone. The data are given in Table 4 along with the differences in nitrogen content of the poorly and better inoculated plants. The differences in nodule production suggest that effective inoculation (100% of plants) had occurred promptly where fine lime was used, while it was delayed significantly where 10-mesh limestone was used. The young plants were larger and richer in nitrogen in consequence of using the finer lime.

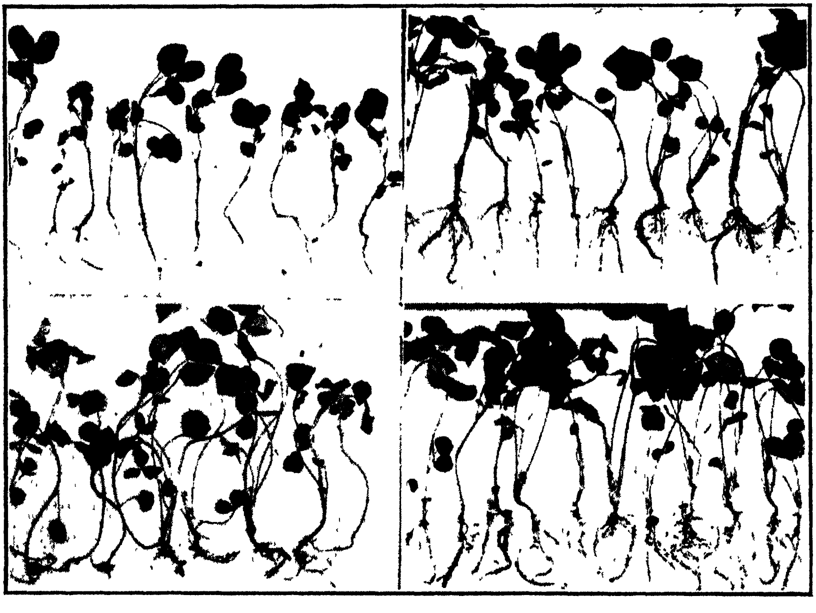

FIG. 2.—Sweet clover (left) and red clover (right) on soil with 10-mesh limestone (above) as compared with soil with 30-mesh limestone (below).

Observations on the condition of the stubble crop emphasized the fact that a good stand of the clover mixture resulted on all the treatments. The 30-acre field receiving 300 pounds of 30-mesh limestone per acre had a stand and growth the equivalent of, if not superior to, that on the 30-acre field receiving 5,000 pounds of 10-mesh limestone per acre. The various treatments on the 1-acre plats did not reveal any significant differences. These plats had all been limed and the different fertilizer treatments made no significant differences.

TABLE 4.—*Nodulation and nitrogen differences in young clovers in consequence of 30-mesh and 10-mesh limestone.*

	10-mesh limestone	30-mesh limestone
Number plants examined..... .	56	51
Nodules per plant: Average	1.6	8.7
Range.	1–19	1–27
Plants inoculated, %	31	100
Dry weight, 50 plants, grams..	0.9796	1.6810
Dry weight per plant, grams	0.0195	0.0336
N, mgm....	27.68	55.38
N, %. .	2.82	3.28*

*Two other samples of plants gathered where 30-mesh lime-stone had been drilled with the seed contained 3.86% and 4.10% of nitrogen, respectively, for plants averaging 0.0438 and 0.0592 gram each.

Apparently no benefit occurred from the use of the rotary hoe ahead of the seeding, although a decided improvement in the crop resulted in that part of the field seeded in the wet soil. As to the reason for the better crop when seeded on the wet soil, none is offered. However, it can scarcely be attributed to better seed cover since equally as deep a cover of the seed was brought about on the dry soil by means of the rotary hoe. A study of the cross section of soil under the row drilled through the wet soil revealed the placement of the lime in a wedge-shaped form. A U-shaped neutral area extending to a depth of about 2½ inches below the soil surface occurred around this limed and wedge-shaped section. Tests of the remaining area of the soil section showed the original degree of acidity for this soil. Hydrogen-ion measurements on the successive strata made the year previous where varying amounts of fine lime had been applied are given in Table 5. These measurements show that the neutralizing effect of the lime is not extensive in the soil zone and that the change in soil reaction is confined to a very limited soil area.

SEASONAL IRREGULARITIES

The success of the crop through the use of so small an amount of limestone as 300 pounds per acre is particularly interesting in view of the unusual seasonal conditions of 1929, especially when contrasted with those of 1928. The spring of 1929 had an extremely high rainfall, extending through the month of May, which had a total precipitation of 10 inches. This season was followed by a very dry summer, having only one significant rain of 0.5 inch on July 17 and less than 0.75 inch from July 1 to September 5. The severity of this drought held down the yields of other crops on this soil type on the same farm to 7 bushels of corn and 3 bushels of soybeans. In spite of these very unfavorable conditions the application of the small amount of lime established the clover.

TABLE 5.—*Profile reactions (pH) at varying depths directly below the limed clover row.*

Depth of sample in inches	No lime			300 pounds 30-mesh			500 pounds 30-mesh		
	pH*	Exchangeable† Base	Exchangeable† Calcium	pH	Exchangeable† Base	Exchangeable† Calcium	pH	Exchangeable† Base	Exchangeable† Calcium
0–1	5.33	5.60	5.02	6.60	9.00	8.68	7.00	10.50	9.26
2–3	5.76	4.70	5.06	5.57	5.60	5.20	5.50	6.00	5.20
4–5	5.59	6.10	5.30	5.51	6.10	4.97	5.43	6.50	5.06
6–7	5.25	6.40	4.77	5.14	6.20	4.25	5.32	5.50	4.32

*According to the hydrogen electrode method.

†According to the Kappen (4) method and expressed as milli-equivalents per 100 grams of soil.

The stubble crop of the trials of 1928 revealed that the fine lime treatment was equally as effective under seasonal conditions quite the reverse of those in 1929, namely, a dry spring followed by a wet summer. May 1928 had a rainfall of only 0.09 inch and was followed by a total rainfall of 20.51 inches from June to August. With this wet summer, the clover stand was excellent where but 300 pounds of the finer limestone was used. This indicates a reduction of the drought hazard to the young clover on this shallow soil where the dry summers are often disastrous to other crops.

SUMMARY AND CONCLUSIONS

Extensive field trials of amounts of lime as small as 300 pounds of 30-mesh material per acre combined with inoculated soil and drilled with the clover seed demonstrated by trials of 3 years that this treatment was as effective as 5,000 pounds of 10-mesh limestone broadcast for establishing the clover crop on a lime-deficient soil (Gerald silt loam).

The use of small amounts of fine lime drilled with the seed was effective in establishing both red and sweet clovers. On account of defective sweet clover seed, this crop was included in only two years of this study. The fine lime produced crops of sweet clover as good as those produced by the heavy applications of the 10-mesh stone, while the crops of red clover were usually superior under the treatments with the 30-mesh stone.

The use of the finer lime hastened the development of thorough inoculation on the roots of the clovers and served to establish them more quickly through this aid on this soil of depleted fertility.

The results of this study raise doubt as to whether it is necessary to neutralize completely the acidity of the surface soil for the successful growth of clover and suggest that it may be necessary to provide only certain limited areas of limed soil accessible to the clover roots.

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A DEFECTIVE SEED-COAT CHARACTER IN SOYBEANS[1]

Ralph T. Stewart and John B. Wentz[2]

During their breeding and genetic studies with soybeans (*Soja max*), the authors observed a defective seed-coat character in one of their crosses. Data were taken on the inheritance of the character and an attempt is made in this paper to interpret these data.

Piper and Morse (2)[3] reported that a number of black and brown varieties of soybeans were introduced from Korea which had the outer layer of the testa cracked so as to expose the inner white layer of the seed. In one variety, Widower, which had a black seed-coat, the splitting occurred in such a way as to give a net-like appearance of black and white color to the seed. The character reported in the present paper is very similar to, or possibly identical with, the one described by Piper and Morse.

DESCRIPTION OF THE CHARACTER

Fig. 1 shows photographs of normal and defective seeds. The seeds in A are brown in color and have normal seed-coats. It was observed that plants bearing brown or black seeds never exhibited the defective seed-coat character. Plants bearing buff or imperfect-black seeds exhibited the defective seed-coats as shown in B of Fig. 1. The seed-coats are "netted" and cracked in varying degrees. The cracks tend to occur more commonly around the edges of the cotyledons. Many of the seeds were split in threshing, due to the fact that the seed-coat was cracked practically all the way around the seed. The buff-colored seeds seemed to split more than the imperfect-black seeds.

The seeds in C of Fig. 1 are yellow mottled with buff pigment. It will be noted that there is some splitting of the seed-coat in the buff areas. Yellow seeds mottled with imperfect-black pigment behaved in the same manner.

ORIGIN OF CHARACTER

Certain F_2 plants from the cross Wisconsin Black x Mandarin bore seeds with defective seed-coats. From this cross eight different color types appeared in the F_2 generation, *viz.*, yellow mottled with

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[3] Reference by number is to "Literature Cited," p. 662.

black, yellow mottled with imperfect-black, yellow mottled with brown, yellow mottled with buff, black, imperfect-black, brown, and buff. The only colors which showed the defective seed-coat character distinctively were imperfect-black and buff. Yellow seeds mottled with either of these two colors showed some splitting of the seed-coat in the pigmented areas.

INHERITANCE OF DEFECTIVE SEED-COAT

The fact that the defective seed-coat character is fully expressed only in plants bearing imperfect-black and buff seeds, and to a slight extent in the pigmented areas of beans mottled with these two colors indicates that the character is in some way associated with a factor for imperfect-black and buff pigments and is inhibited by the factor for yellow pigment.

Stewart (5) has shown that buff pigment is due to the interaction of two recessive color factors, r_1 and r_2. Since both imperfect-black and buff colors contain the recessive color factor r_2, it appears that possibly r_2 might also cause the defective seed-coat character. This is not likely, however, since buff color in soybeans has been described by Nagai (1) and by Owen (3 and 4), but no mention was made by these authors of a defective seed-coat character. Another reason for believing the factor causing the defective seed-coat character to be different from the factor for buff color is that the variety Widower described by Piper and Morse (2) as having a defective seed-coat had black seeds and, therefore, did not contain the factor for buff or imperfect-black seed-coat. It seems, then, that an explanation other than to assume that the defective seed-coat character is caused by the factor for buff color is desirable.

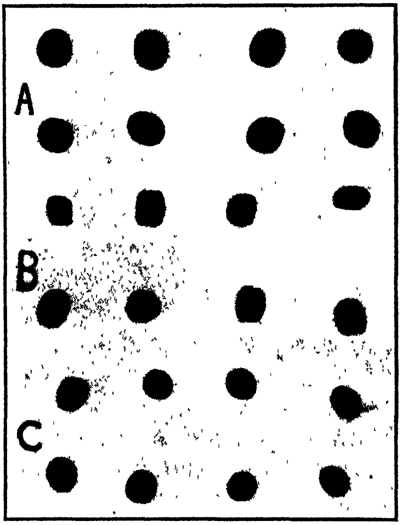

FIG. 1.—A, brown, normal seeds borne on an F_2 plant in a progeny segregating for the defective seed-coat; B, buff-colored, defective seeds from a plant in the segregating F_2 progeny; C, yellow seeds mottled with buff pigment, borne on an F_2 plant in the segregating progeny, showing the defective seed-coat in the buff areas.

Owen (3 and 4) and Stewart (5) have shown that imperfect-black and buff pigments occur only in the seed-coats of plants having gray pubescence. In the present study all plants which bore defective seeds had gray pubescence, while plants with tawny pubescence bore normal seeds. By assuming complete linkage between the factor T, for tawny pubescence, and a factor De, for normal seed-coat, the occurrence of the defective seed-coat character only on plants with imperfect-black and buff colored seeds can be explained.

It has already been shown by Stewart (5) that in this cross a factor I inhibits any of the above pigments to give a yellow, mottled seed-coat color. With the same factor operating to inhibit the expression of a recessive gene, de, causing the defective seed-coat character, and independent of I, a 15:1 ratio of plants bearing normal and defective seeds would be expected in the F_2 generation. Actual counts showed 51 plants bearing seeds with normal seed-coats to 5 with defective seed-coats. For a 15:1 ratio there should have been 52.5 plants in the first class and 3.5 plants in the second class. With 56 plants, the deviation from the expected is only 1.50 ± 1.22. If we assume that De represents the factor for normal seed-coat and its recessive allelomorph, de, the factor for splitting, then the above results can be explained by the following interaction of factors:

9 I De—normal
3 I de—normal (except for pigmented areas of beans mottled with buff or imperfect-black)
3 i De—normal
1 i de—defective

In order to verify the classification of the F_2 plants, 51 of the plants were tested in the F_3 generation. Of these 51 plants, 5 were plants bearing seeds with defective seed-coats and 46 were plants bearing seeds with normal seed-coats. According to the hypothesis proposed, the 5 plants bearing defective seeds would be expected to breed true. From the 46 plants bearing normal seeds one would expect to obtain progenies pure for normal seeds, progenies segregating in a 15:1 ratio, and progenies segregating in a 3:1 ratio. These progenies would be expected to appear in the ratio of 7:4:4. The plants in the progenies from the 5 F_2 plants bearing defective seeds all bore defective seeds as expected, and the 46 plants bearing normal seeds gave progenies as shown in Table 1. Twenty-six of the 46 progenies were homozygous for normal seeds, 10 progenies segregated in a 3:1 ratio, and 10 progenies segregated in a ratio of 15:1. On the basis of the theoretical ratio of 7:4:4, there should have been 21.49 homozygous progenies to 12.28 progenies segregating in the 15:

1 ratio to 12.28 segregating in the 3:1 ratio. In comparing the actual numbers with the theoretical numbers, the values of X^2 and P are 1.99 and 0.37, respectively.

TABLE 1.—*Breeding behavior of F_2 plants having normal seed-coats.*

	F_3 phenotypes		
F_2 plant No.	Normal	Defective	Dev. P.E.
	Homozygous Progenies		
1	17	—	—
2	68	—	—
3	31	—	—
4	22	—	—
5	52	—	—
6	30	—	—
7	84	—	—
8	96	—	—
15	27	—	—
19	99	—	—
20	83	—	—
21	27	—	—
25	33	—	—
27	19	—	—
28	63	—	—
30	30	—	—
33	35	—	—
38	93	—	—
44	55	—	—
46	58	—	—
51	61	—	—
53	30	—	—
57	53	—	—
58	31	—	—
60	57	—	—
61	64	—	—
Total 26	1,309	—	—
	Segregating Progenies, 15:1 Ratios		
12	62	4	0.09
31	64	8	2.51
35	57	4	0.15
36	61	4	0.05
37	53	5	1.11
40	49	3	0.21
48	17	2	1.14
50	47	4	0.69
52	29	1	0.98
56	11	1	0.44
Total 10	450	36	1.56
	Segregating Progenies, 3:1 Ratios		
13	81	27	0.00
17	56	10	2.74
18	13	2	1.55
23	119	30	2.03
26	24	7	0.46
32	13	5	0.40
41	19	6	0.17
45	56	9	3.09
54	42	21	2.26
55	51	14	0.96
Total 10	474	131	2.82

SUMMARY

1. A recessive gene, de, which causes a defective seed-coat character in soybeans was observed in the progeny from a cross between two varieties of soybeans.

2. In the F_2 generation, a ratio of 15 plants bearing seeds with normal seed-coats to 1 bearing seeds with defective seed-coats was obtained. In the F_3 generation, F_2 plants with defective seed-coats bred true and F_2 plants bearing seeds with normal seed-coats produced progenies in the proportion of 7 breeding true for normal seeds to 4 segregating according to a 15:1 ratio to 4 segregating according to a 3:1 ratio.

3. The factor I which inhibits pigment colors, giving yellow seed-coats, also inhibits the gene de for defective seed-coat.

4. The factor de showed complete linkage with the factor t for gray pubescence. All plants bearing seeds with defective seed-coats had gray pubescence.

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NITRATE FERTILIZERS FOR OATS IN IOWA[1]

RAY A. PENDLETON[2]

Iowa is known chiefly as a corn state and it is but natural that the major part of the experimental field work in the state has been done on corn. However there is a very large acreage of oats grown each year and some information regarding the profit from the use of commercial fertilizers for oats would be very desirable. Since very few experiments have been carried out in the state on fertilization with nitrogen, this experiment was begun with a view to obtaining information regarding the effect of sodium nitrate on oats on some of the more extensive Iowa soils.

The experiment was planned to study the effect of sodium nitrate applied in different amounts and at different times on the yield and protein content of oats.

Experiments in this and other countries on various soils have generally shown that the nitrogen content of oats can be increased by nitrogen fertilization. The increases in yield due to fertilization naturally vary according to the fertility of the soil.

Wiley (11)[3] in 1898 found that oats grown on moor soils contained about 25% more nitrogen than oats grown on ordinary soils. He attributed the increased nitrogen content to the greater amount of nitrogen in the moor soils.

Kruger (8) in 1905 fertilized oats with sodium nitrate more than doubling the yield and nearly doubling the nitrogen content. He obtained 0.95% nitrogen for untreated oats and 1.56% nitrogen for treated oats.

Thatcher and Arny (9) in 1917 increased the nitrogen content of oats by treatments with sodium nitrate and they also found that oats following clover had a higher protein content than oats following oats.

Gericke (5) in 1922 applied sodium nitrate to oats at the rate of 82 pounds of nitrogen per acre at varying intervals of time after planting. He obtained the highest yield when the fertilizer was applied 90 days after planting, and the highest protein content when the fertilizer was applied 118 days after planting.

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[2] Graduate Assistant. The author wishes to express his appreciation for the assistance given by Dr. P. E. Brown and Dr. F. B. Smith in outlining this work and to the Chilean Nitrate of Soda Educational Bureau under whose auspices the work was made possible.

[3] Reference by number is to "Literature Cited," p. 668.

Appleton and Helms (1) in 1925 studied the rate of absorption of nitrogen from sodium nitrate by oats at different stages of growth and found that the later applications of nitrogen were more efficiently and quickly used by the oats and also produced the highest yields. Helms (6) also studied the effect of different times of application of sodium nitrate on the yield of oats in Alabama and found that the time of application may be fully as important as the amount applied.

Balashev (2) and Kazakov (7) in 1926 in their reports of experimental work in Russian provinces comment on the very notable response of oats to nitrogen fertilization.

Buie, *et al.* (3) in 1927 experimented with fall oats in South Carolina and obtained the highest yields with 300 pounds of sodium nitrate. When this amount was applied in March, the yield was 5 bushels more per acre than when it was applied at planting time and 4 bushels more than when it was applied in April. They obtained slightly higher yields with sodium nitrate than with any other nitrogen fertilizer used. Calcium nitrate was second.

Ferris and Anderson (4) in 1927 found that January applications of nitrogen fertilizers in Mississippi were much more effective on oats than February or March applications.

White and Gardner (10) in 1928 obtained marked increases in yields of oats in Pennsylvania due to nitrate fertilization, using sodium nitrate at the rate of 300 pounds per acre. They claimed that the increase in yield due to nitrogen fertilizers was a function of the nitrogen content of the soil. They obtained an increase in yield of 18% with nitrate fertilizers on the Westmoreland soil and a much smaller increase on the Volusia soil.

The above partial review of the literature shows that there may be possibilities of appreciably increasing either the yield of grain or the protein content of oats on certain soils with proper fertilization. With these possibilities in mind an experiment was begun, first under greenhouse conditions and later with field plats, to study the problem.

GREENHOUSE EXPERIMENT

For the greenhouse work, Shelby loam soil was potted into 4-gallon earthenware pots on January 7, 1929, and the fertilizer was added on an acre basis. Oats were planted at a uniform depth and, when well started, were thinned out to 15 plants per pot. Table 1 gives the general plan of the experiment.

The soil at the beginning of the experiment contained 10 p. p. m. of nitrate nitrogen.

TABLE 1.—*Treatments of the pots in the greenhouse.*

Pot No.	Treatments on acre basis
1 & 1A	Check
2 & 2A	100 pounds nitrate Jan. 7
3 & 3A	100 pounds nitrate March 10
4 & 4A	100 pounds nitrate April 22
5 & 5A	200 pounds nitrate Jan. 7
6 & 6A	200 pounds nitrate March 10
7 & 7A	200 pounds nitrate April 22
8 & 8A	200 pounds nitrate Jan. 7 plus 120 pounds superphosphate.
9 & 9A	200 pounds nitrate Mar. 10 plus 120 pounds superphosphate Jan. 7
10 & 10A	50 pounds nitrate Jan. 7 plus 50 pounds March 10
11 & 11A	50 pounds nitrate Jan. 7 plus 50 pounds April 22
12 & 12A	50 pounds nitrate Jan. 7 plus 100 pounds Mar. 10 plus 50 pounds April 22
13 & 13A	100 pounds nitrate Jan. 7 plus 100 pounds March 10
14 & 14A	100 pounds nitrate Jan. 7 plus 100 pounds April 22

The oats were kept watered and allowed to grow to maturity and were well ripened before they were harvested. The crop in all the pots was in good condition at harvest time, with the exception of that in pots Nos. 8, 8A, 9, and 9A. In these pots the oats were a few days earlier than the others and were somewhat damaged by mice and sparrows. As a result the yields, particularly of 8 and 8A, are not representative of the treatments.

Since all treatments were made in duplicate, the results given in Table 2 are averages of duplicate treatments.

TABLE 2.—*The yields of grain and straw and the protein content of oats grown under greenhouse conditions.*

Pot No.	Total weight of plants in grams	Total weight of grain in grams	N %
1	60.25	13.55	2.43
2	60.00	11.65	2.79
3	64.25	16.55	2.49
4	52.25	15.26	2.70
5	68.00	17.35	2.52
6	85.00	21.92	3.19
7	71.75	16.12	3.03
8	87.00	16.38	1.84
9	77.50	13.85	2.61
10	62.50	10.38	2.79
11	63.50	17.65	2.43
12	52.58	13.42	2.65
13	66.00	11.75	2.85
14	58.00	10.48	3.03

An examination of the data shows that unquestionably the later applications of the nitrate increased the protein content of the grain. The exceptionally low results from pot No. 8 were doubtless due to the fact that the grain was destroyed to some extent and harvested too early. Where the yield only is considered, the phosphate and nitrate together showed an unmistakable effect. There was no indication, however, that phosphate gave any increase in the protein content.

The late applications of nitrate seemed to delay maturity, and in pots Nos. 4, 7, and 14 there was a tendency for a second growth of new shoots to start. The increase in yield from the heavy applications over that brought about by the light applications appears to be rather variable and more data are necessary before definite conclusions can be drawn.

FIELD EXPERIMENT

The general plan of the field experiment is given in Table 3. For this phase of the work a field of Carrington loam soil was selected and 1/20-acre plats were used. The fertilizer was applied broadcast by hand and the plats sown to oats April 26, 1929.

TABLE 3.—*Plan of field experiment.*

Plat No.	Treatment on acre basis
1	Check
2	100 pounds nitrate April 26
3	100 pounds nitrate June 17
4	100 pounds nitrate July 1
5	200 pounds nitrate April 26
6	200 pounds nitrate June 17
7	200 pounds nitrate July 1
8	200 pounds nitrate April 26 plus 120 pounds superphosphate
9	200 pounds nitrate June 17 plus 120 pounds superphosphate
10	50 pounds nitrate April 26 plus 50 pounds July 1
11	50 pounds nitrate April 26 plus 100 pounds June 17 plus 50 pounds July 1
12	100 pounds nitrate April 26 plus 100 pounds June 17
13	100 pounds nitrate June 17 plus 100 pounds July 1
14	100 pounds nitrate April 26 plus 100 pounds July 1
15	Check

At the time of harvest and even earlier there was a very noticeable difference in the height of the straw on the various plats. On plat 8 the straw was more than twice the height of that on the check plats. There was some difference in the rate of maturity but not sufficient to be important. The results of the experiment are summarized in Table 4.

TABLE 4.—*Results of field experiment on oats on Carrington loam.*

Plat No.	Yield in bushels per acre	Weight per bushel, pounds	N %
1	29.23	31.0	1.73
2	66.33	32.0	1.81
3	52.75	35.0	1.94
4	34.03	34.5	2.02
5	44.20	35.0	2.18
6	32.31	33.5	2.06
7	40.84	33.0	2.06
8	78.00	36.0	2.48
9	39.10	35.5	2.24
10	36.78	32.5	1.88
11	44.20	34.5	1.93
12	52.75	34.0	1.97
13	40.84	33.0	2.04
14	57.85	33.0	2.04
15	39.10	33.0	1.84

The average yield on the two check plats was 34.16 bushels per acre. Plat 8 which had the early treatment of nitrate plus the phosphate yielded slightly more than double this amount. This plat showed a large margin of profit from the use of the fertilizers. The quality of the oats from plat 8 was also decidedly better both in weight and percentage of protein than that from the check plats. From the results on plat 9 it may be concluded that treatment with superphosphate alone is hardly sufficient to bring about much increase. Assuming that the total increase in yield on plat 9 was due to the superphosphate, there was only about a 5-bushel increase, whereas early application of the nitrate plus the phosphate gave a 44-bushel increase.

The average increase in yield on plats 2, 12, and 14, each of which received an initial application of 100 pounds of sodium nitrate, was approximately 25 bushels per acre over the checks. The average increase on plats 10 and 11, which received an initial application of 50 pounds of sodium nitrate, was approximately 6 5 bushels per acre over the checks. The average increase in yield on plats 3, 4, and 13, each of which received 100 pounds of sodium nitrate but no early application, was approximately 8.5 bushels per acre, or about equal to the results with 50 pounds added in the early application. The late applications of 200 pounds of sodium nitrate on plats 6 and 7 had little effect on the yields. There was some tendency toward a late straw growth on these plats and a lack of setting of grain.

The data on the protein content of the grain from the various plats indicate some increases in protein content with the later applications of nitrate, but these were not great enough to make up for the extra yield which would have been obtained from the same quantity of fertilizer applied early. The data as a whole indicate that an application of 100 pounds of sodium nitrate was all that could be profitably used unless superphosphate was added in addition. The data also indicate that superphosphate without nitrate had little effect. When superphosphate was used, heavier applications than 100 pounds of sodium nitrate appeared to be advantageous. The earlier applications of nitrate appeared to be much better than the late applications.

The data from both the field and greenhouse experiments show that the protein content of oats grain can be appreciably altered by nitrate fertilization. Both experiments indicate that late applications of nitrate will increase the protein content slightly more than early applications. Although in general the protein content of the field grain is considerably lower than that of the greenhouse grain, the general trend of the results is the same.

The yields on the field plats are rather remarkable and probably exceptional, due to a rather late wet spring and other seasonal conditions.

SUMMARY AND CONCLUSIONS

1. Two series of nitrate fertilization experiments with oats were conducted. One was on Shelby loam in greenhouse pots and the other on Carrington loam in the field.
2. The results of both series indicate that early applications of sodium nitrate to oats may appreciably increase the yield.
3. Early applications of the nitrate were more effective in producing an increase in yield than late applications.
4. In both series an increase in the nitrogen content of the grain was obtained from both early and late applications of sodium nitrate, the late applications being more effective than the early applications.
5. The use of superphosphate without nitrate had little effect on the oats.
6. Applications of sodium nitrate at the rate of 200 pounds per acre, particularly if applied late, tended to produce a late growth of straw and delayed maturity. However, the field results indicated that this amount might be used to advantage if applied in connection with superphosphate.

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BOOK REVIEWS

HANDBUCH DER BODENLEHRE (HANDBOOK OF SOIL SCIENCE)

I. THE UNDERLYING PRINCIPLES OF SOIL FORMATION

E. Blanck, Editor. Berlin: J. Springer. 335 pages, illus. $6.75 unbound; $7.40 bound. 1929.

Soil science has ceased to be a private hunting ground for agronomists. Representatives of other professions, particularly the geologists, botanists, mineralogists, and biologists, are also interested in soils and have made numerous and valuable contributions to this new science. Agronomists often wish to keep in touch with these studies, but few have opportunity, time, and ability to read regularly over a hundred periodicals, written in many different languages.

Prof. E. Blanck of the University of Gottingen has undertaken the difficult but highly commendable task of gathering the wealth of existing data and knowledge on soils, and publishing it in the form of a comprehensive "handbook" to consist of 10 volumes. The editor is assisted by a staff of 49 scientists, many of them having an international reputation. According to announcements made, seven volumes will be devoted to theoretical soil science and three volumes to applied soil science (soil technology). The scope of the work may be compared with Waksman's "Principles of Soil Microbiology," except that it covers the entire field of soil science.

In Volume I, in two introductory chapters, E. Blanck gives an interesting, and partly philosophical discussion of "soil science coming of age," while F. Giesecke offers a historical review on the development of soil science until the beginning of the 20th century. On page 87 the broad field of soil formation is taken up, but in this first volume only parent material and factors operating during soil development are dealt with. The section on parent·material is divided into "minerals" and "rocks" (both by F. Heide), "material from the atmosphere" (by W. Meigen), and "organic substances" (by K. Rehorst).

The following factors influencing weathering are discussed: "physical forces" (by H. Fesefeld), "chemical forces" (by G. Hager), and "geological forces." The latter group has been split up into "effects of running water," "effects of oceans" (both by L. Rueger), "effects of ice and glaciers" (by H. Phillipp), "wind influences" (by S. Passarge), and "denudation" (by L. Rueger).

Generally speaking, this first volume is a good beginning, although not every part seems equally well written. In the chapter on rocks, for instance, the modern way of expressing the chemical composition of rocks in the form of graphs, triangles, and ratio figures is favorably emphasized, while the presentation of chemical forces including colloid-chemical reactions is less up-to-date. Again, the treatise on glacial actions is written in masterly fashion, and the section on wind influence reads like a fascinating story. Illustrations, type, and paper conform to the high standard set by the publisher. (H. J.)

EXPLORING FOR PLANTS

By David Fairchild. New York: Macmillan Co. XX + 591 pages, illus. 1930. $5.

To those who have had the good fortune to hear some of the public addresses of the author of this unusual book, it will not be at all surprising that he has succeeded in making a most readable contribution to the increasing volume of so-called "popular science" literature. Quick to set forth at once the purpose of the book, the author states in the opening sentence of his introduction that, "It attempts to interest the layman with adventures that are not any of them hairbreadth escapes, and it seeks to give information about plants to the botanists and horticulturists in a popular form. The result will perhaps be to bring down on my head the criticism of my botanical friends, who will find some misspelled or obsolete scientific names, and of my lay friends who will think I have put in too many dry uninteresting Latin names which they cannot pronounce."

The book is essentially a diary of the Allison Vincent Armour expeditions of 1925, 1926, and 1927 for the collection of plants for the United States Department of Agriculture, the permanent records of which, as the author points out, will be found in the printed files of the Office of Foreign Plant Introduction and in the thousands of specimens, living and dried, brought back by the Expedition and which now form a part of the equipment of that Office for the improvement of American agriculture.

The volume is copiously illustrated, chiefly from photographs made by the author, and is especially attractive typographically and in its mechanical make-up. Despite its purely popular character, the large amount of information assembled here is certain to make this a valuable reference work for the botanical and horticultural library. (J. D. L.)

THE APPLICATION OF SCIENCE TO CROP PRODUCTION

By Albert Howard and Gabrielle L. C. Howard. New York: Oxford University Press. 81 pages, illus. 1929. $3.

This brief monograph will probably be of chief interest to those charged with the administration of agricultural research institutions, for it deals largely with the organization, expenditures, and accomplishments of the Institute of Plant Industry founded at Indore, India, in 1924, although agronomists interested in cotton will also find in its pages much of value in their field. The Indore Institute is unique in that it is an expression of the opinion that the organization of an agricultural research institute on the basis of practical agriculture, on the one hand, and on the basis of the separate sciences, on the other, is not an ideal arrangement. This led to the foundation of an Institute for crops at which the development of the plant, in this case cotton, could be studied as a biological whole.

The chief purposes of the Institute of Plant Industry at Indore are given as (a) the fundamental investigation of cotton and a critical study of cotton growing on the black soils of India, together with the production of improved cottons for central India, both for dry and irrigated lands; (b) the training of post-graduate students; and (c) the provision of a demonstration of the possibilities of development of this portion of India. The senior author is Director of the Institute, and together the authors have devoted the past twenty-five years to a study of the means by which botany could profitably be applied to the crops of India. A list of their papers published since 1905 is appended and serves to illustrate the nature and scope of their investigations. (J. D. L.)

AGRONOMIC AFFAIRS

NORTHEASTERN STATES PASTURE CONFERENCE

According to a report summarized by T. E. Odland, chairman of the conference report committee, agronomists and representatives from 12 northeastern states and the U. S. Dept. of Agriculture met in Amherst, Mass., May 27 and 28, 1930, at the invitation of Director F. J. Sievers of the Massachusetts Agricultural Experiment Station, for a discussion of pasture problems. The discussions centered around four topics, as follows: 1. The service of chemistry to pasture problems, led by J. G. Archibald, of the Department of Chemistry, Massachusetts Agricultural College; 2. fertilizer practices, led by G. L. Schuster of the Delaware Agricultural Experiment Station; 3. measurements for pasture experiments, led by F. D. Gardner of Pennsylvania State College; and 4. grazing problems, led by B. A. Brown of the Connecticut Agricultural College.

It was the opinion of the conference that chemistry has a very definite and valuable service to render to this problem. The other three topics appear to have many variables and for that reason work done on them should be aimed at fact finding rather than at a solution of current economic and farm management problems. All discussions were informal and were heartily entered into. Both afternoon sessions were given over to inspection of the pasture work of the Massachusetts Agricultural College.

PAMMEL STATE PARK

On June 30, services were held for the dedication of Pammel State Park in Madison County, Iowa. This park, formerly known as Devil's Backbone State Park, has been rechristened Pammel State Park in recognition of the services rendered the State of Iowa by Dr. Louis H. Pammel, the first chairman of the Iowa Board of Conservation and for many years an ardent advocate of the State park system. The park comprises 225 acres, and is said to contain many interesting geological and botanical features.

NEWS ITEMS

George W. Patteson, District Manager, Washington office of the Chilean Nitrate of Soda Educational Bureau, resigned his position with the Bureau, effective July 1, to return to the Virginia Agricultural College, Blacksburg, Va., to have charge of soils work which the Experiment Station began on July 1.

F. D. STEVENS formerly sugar cane agronomist with the U. S. Dept. of Agriculture, was recently appointed Associate Agronomist and assigned to sugar cane agronomic work at the Everglades Experiment Station, Belle Glade, Florida.

JOHN P. CAMP, was appointed Assistant Agronomist at the Florida Agricultural Experiment Station at Gainesville, effective May 15.

OSCAR F. BARTHOLOMEW, fellow in soils at the Oregon State College, who recently completed requirements for the Master's degree, has received an appointment as Soil Surveyor with the U. S. Bureau of Chemistry and Soils and is reporting for field work in Montana.

W. L. POWERS will represent the Oregon State Agricultural Experiment Station at the Second International Soil Congress in Leningrad and Moscow in July. He has been granted sabbatical leave and plans to return to Washington, D. C., in October, where he will study and do some writing.

R. E. STEPHENSON has returned to Oregon State College after a sabbatical year spent in study in California.

OREGON STATE COLLEGE has purchased 244 acres of representative Willamette silt loam 4 miles north of the campus for a new agronomy farm. This new farm will be used for soil building, rotation, fertility, and tillage experiments and also for a variety of tests and plant breeding work of the Crops Department.

THE WESTERN SOCIETY OF SOIL SCIENTISTS held a very successful meeting at the Oregon State College June 16 to 18 at which two dozen papers centered around the topics of ground water, development of nitrogen and humus problem, alkali land reclamation, and chemical tests for determining nutrient deficiencies in soils. H. P. Magnuson of the Idaho Experiment Station was elected President; E. E. Thomas of Riverside, secretary; and Director L. D. Bachelor of the Riverside Experiment Station, treasurer. The next meeting of the Society will be held at Riverside just ahead of the annual meeting of the Pacific Division of the A. A. A. S. A report was accepted disapproving patenting for private gain where discoveries are made from research maintained with public funds. This originated from general disapproval of an attempt to restrict by patent conversion of farm wastes into artificial manure.

H. E. BREWBAKER, formerly Assistant Plant Geneticist at the University of Minnesota, has accepted a position as Associate Agronomist with the Office of Sugar Plants of the U. S. Dept. of Agriculture, and will be stationed at Fort Collins, Colorado.

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SODIUM NITRATE AS A FERTILIZER FOR CORN ON IOWA SOILS[1]

R. A. PENDLETON[2]

The large acreage of corn in Iowa and other middle west states and its agricultural importance has naturally led to many investigations of methods of increasing the yield and quality of the crop. There are several means which may be employed. The selection of varieties and the control of weeds, insects, and diseases are in the field of other workers and will not be discussed in this article. This work is concerned with the improvement of the soil so that, other conditions being equal, more corn per acre may be produced.

During the years of 1869 to 1907 there were 6,394 tests with various fertilizers for corn made in the United States. Of these, 249 were with sodium nitrate. The data from these tests were collected and summarized by Whitney[3] in 1910. He found from the yields with the sodium nitrate tests, that the ratio of increases over no effects was 2.3 to 1, but that the average net loss per acre from the use of the fertilizer was $3.06. Where superphosphate was used in addition to sodium nitrate the net loss was reduced to $0.40 per acre. On the average, the better soils showed about as large increases as the poorer soils.

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[1] Contribution from the Department of Soils, Iowa State College, Ames, Iowa. Received for publication March 21, 1930.

[2] Graduate Assistant. The author wishes to express to Dr. P. E. Brown his sincere appreciation of the assistance rendered in the preparation of this article and to Dr. F. B. Smith for his helpful suggestions in planning the work. Acknowledgment is also made of indebtedness to H. R. Meldrum, A. J. Englehorn, and Roy E. Bennett for their valuable assistance in the field work. Thanks is also tendered to the Chilean Nitrate of Soda Educational Bureau under whose auspices the work was made possible.

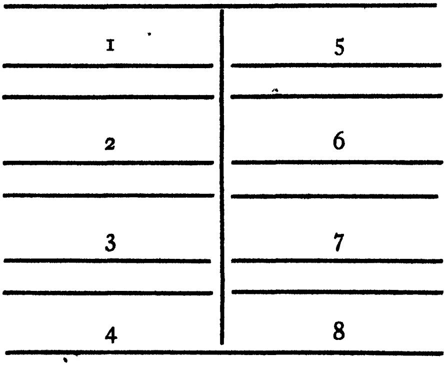
[3] WHITNEY, M. Fertilizers for corn soils. U. S. D. A. Bur. of Soils Bul. 64. 1910.

In more recent years considerable work has been done in Alabama, particularly by Duggar and Williamson,[4] relative to the fertilization of corn with sodium nitrate. Their recommendations were to apply the nitrate when the corn was 2½ to 4 feet high for the most economical returns. Some previous work on the more productive soils of Iowa failed to show economical returns from the use of nitrate for corn.

EXPERIMENTAL

In the spring of 1929 it was decided to test the action of sodium nitrate on corn on several different soil types of Iowa, and particularly on some of the less productive types. Accordingly, several fields were selected in different parts of the state on which these tests could be made.

Four plats 28 by 155½ feet, with a border strip between plats, were established on each field. Across one end of the plats so as to include one-half of each, superphosphate was applied at the rate of 120 pounds per acre. Plat 1 received sodium nitrate at corn planting time at the rate of 100 pounds per acre. Plat 2 received two 50-pound applications, the first at corn planting time and the second about July 1. Plat 3 received 100 pounds of sodium nitrate about July 1. These nitrate applications were made the full length of the plats including the phosphated end. Plat 4 was left untreated as a check. In this manner there were eight plats of 1/20 acre size established for each field. The following diagram shows the arrangement of the plats:



Plats 5, 6, 7, and 8 are the phosphated portions. All fertilizer applications were made broadcast by hand.

Plats were located on 16 fields and included nine soil types. In harvesting, the corn from the center half of each plat was picked and weighed separately. The yield per acre was then calculated on a basis of either 75 or 80 pounds per bushel of corn, depending on the state of dryness. In an attempt to compare all plats on a uniform basis, a perfect stand was harvested for each plat, i.e., when missing hills were encountered this method tended to give an apparent yield somewhat higher than the actual yield but was more uniform for all plats. On field 9 at Waverly, the number of missing hills was rather excessive and the results are misleading.

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[4] DUGGAR, J. F., and WILLIAMSON, J. T. Local fertilizer experiments with corn in south Alabama. Ala. Agr. Exp. Sta. Bul. 181. 1914.

At harvesting time some samples of corn were taken from plats 1, 3, and 4 of several of the fields and analyzed for total nitrogen, with the object of ascertaining if the different treatments materially affected the protein content of the corn.

Unfortunately, it was not possible to obtain results from all of the fields as the plats in some cases were damaged by stock or otherwise destroyed so that harvesting was either impossible or useless. The yields from each field harvested and the nitrogen content of such samples as were taken are given in Table 1.

The average yield of the 11 fields that were harvested was 45.6 bushels per acre for plat 1, 47.8 bushels for plat 2, 46.7 bushels for plat 3, and 41.6 bushels for plat 4. This was an increase of about 5 bushels per acre for the nitrate. The divided application gave the highest yield and the late application was second highest, but these differences due to different times of application were hardly large enough to be very significant.

When superphosphate was used in addition to the nitrate, the yields were 47.9 bushels for plat 5, 46.1 bushels for plat 6, 46.3 bushels for plat 7, and 43.1 bushels for plat 8. The differences from the nitrate on this series are a little smaller, although they show the same general tendency, except that the early application was the most effective in this case. In this season there did not seem to be any evidence of benefit from the use of superphosphate. This is likely due to abnormally dry weather conditions. The superphosphate tended to push the corn into the earlier maturing stage, and as it was further along when the dry weather came it seemed to be damaged more than the later corn. Thus, on some fields, the superphosphate was detrimental.

On the different soil types tested, the Clinton silt loam appeared to be the most responsive to nitrate fertilization. The average yields on the three fields on this soil type that were harvested were as follows: Plat 1, 54.1 bushels per acre; plat 2, 56.4 bushels per acre; plat 3, 56.4 bushels per acre; plat 4, 44.3 bushels per acre; plat 5, 50.6 bushels per acre; plat 6, 54.8 bushels per acre; plat 7, 52.2 bushels per acre; and plat 8, 42.1 bushels per acre.

TABLE I.—*Results of experiments with sodium nitrate as a fertilizer for corn on different soil types in Iowa.*

Field No.	Location	Soil type	Plat No.	Bushels per acre	N %
I	Everly	O'Neill loam	1	34.0	2.00
			2	35.0	—
			3	36.0	2.03
			4	35.7	1.91
			5	28.7	—
			6	33.0	—
			7	37.5	—
			8	38.7	—
II	Milford	O'Neill loam	Not harvested		
III	Milford	Pierce fine sandy loam	1	35.3	1.88
			2	33.3	—
			3	31.7	1.88
			4	29.3	1.71
			5	30.6	—
			6	31.7	—
			7	32.6	—
			8	31.3	—
IV	Superior	Clarion loam	1	36.7	1.60
			2	35.2	—
			3	34.7	1.68
			4	33.2	1.68
			5	34.0	—
			6	29.0	—
			7	32.0	—
			8	34.0	—
V	Ruthven	Carrington fine sandy loam	1	32.6	1.67
			2	32.0	—
			3	30.3	1.69
			4	29.3	1.77
			5	26.3	—
			6	30.3	—
			7	33.0	—
			8	36.6	—
VI	Hudson	Waukesha loam	Not harvested		
VII	Floyd	Lindley silt loam	Not harvested		
VIII	Marion	Clinton silt loam	1	51.8	—
			2	54.5	—
			3	52.6	—
			4	35.8	—
			5	61.2	—
			6	64.0	—
			7	56.5	—
			8	50.0	—
IX	Waverly	Carrington sandy loam	1	71.0	—
			2	68.2	—
			3	60.0	—
			4	66.9	—
			5	71.6	—
			6	74.8	—
			7	70.1	—
			8	78.0	—

TABLE 1.—*Concluded.*

Field No.	Location	Soil type	Plat No.	Bushels per acre	N %
X	Independence	Carrington sandy loam	Not harvested		
XI	West Liberty	Calhoun silt loam	1	49.3	1.36
			2	59.0	—
			3	50.4	1.31
			4	43.7	1.46
			5	63.8	—
			6	50.0	—
			7	50.2	—
			8	42.2	—
XII	West Point	Marion silt loam	1	37.4	1.41
			2	42.4	—
			3	45.0	1.40
			4	37.8	1.55
			5	46.0	—
			6	50.6	—
			7	51.7	—
			8	47.8	—
XIII	Rome	Clinton silt loam	1	58.3	—
			2	62.7	—
			3	64.5	—
			4	58.2	—
			5	53.8	—
			6	57.8	—
			7	56.6	—
			8	47.8	—
XIV	Osceola	Clinton silt loam	Not harvested		
XV	Osceola	Clinton silt loam	1	52.2	1.60
			2	52.0	—
			3	52.0	1.41
			4	39.0	1.44
			5	37.0	—
			6	42.5	—
			7	43.5	—
			8	31.0	—
XVI	Murray	Shelby loam	1	42.5	—
			2	51.5	—
			3	56.7	—
			4	48.5	—
			5	54.5	—
			6	53.3	—
			7	56.0	—
			8	39.5	—

These data show an average increase in yield of about 10 bushels per acre from the use of sodium nitrate. In these fields the superphosphate gave a slight depression in yield. The divided application gave slightly better results than the early application and about the same as the late application. These data appear to emphasize the need of nitrates all through the growing period.

The average figures for the total nitrogen content of the grain from the different plats show no differences resulting from the fertilizers. For all analyses the corn on plat 1 had an average nitrogen content of 1.64%; on plat 3, 1.62%; and on plat 4, 1.64%.

These data secured from the experiments on the Clinton silt loam show that the use of sodium nitrate as a side dressing for corn in amounts of 100 pounds per acre may be profitable.

One field of Carrington loam was selected near the experiment station farm for some special studies on the results of fertilizing corn with sodium nitrate on this soil type. A portion of this field was used in an experiment to test the action of artificial manures as a fertilizer for corn and use was made of this experiment to test the effect of sodium nitrate when used with these various artificial manures and other carbonaceous plant residues. The general plan of the experiment is given in Table 2.

TABLE 2.—*Fertilization experiment for corn on Carrington loam.*

Plat No.	Treatment
1A	Untreated
1B	100 pounds nitrate per acre July 3
2A	Farm manure 8 tons per acre
2B	Same as 2A plus 100 pounds nitrate July 3
3A	Corn stalks treated with Adco 8 tons per acre
3B	Same as 3A plus 100 pounds nitrate
4A	Oats straw treated with Adco 8 tons per acre
4B	Same as 4A plus 100 pounds nitrate July 3
5A	Oats straw rotted 8 tons per acre
5B	Same as 5A plus 100 pounds nitrate July 3
6A	Untreated
6B	100 pounds nitrate July 3
7	Dry corn stalks 2 tons per acre plus 100 pounds nitrate July 3
8	Dry oats straw 2 tons per acre plus 100 pounds nitrate July 3
9	100 pounds nitrate at planting time
11	100 pounds nitrate hill application at planting time
11	100 pounds nitrate July 3
12	Untreated
13	200 pounds nitrate at planting time
14	200 pounds nitrate July 3
15	100 pounds nitrate at planting time plus 100 pounds July 3
16	50 pounds nitrate at planting time plus 50 pounds July 3

The plats were 1/20 acre in size with a border between plats. Plats 1 to 8, inclusive, of this series were on fall plowing and plats 9 to 16, inclusive, on spring plowing. The spring plowing showed a slightly higher moisture content most of the season. Plats 7 to 16, inclusive, had a field application of superphosphate at the rate of 120 pounds per acre.

This series was harvested and weighed separately October 22, and the yields per acre calculated on a basis of 80 pounds of corn per bushel. Samples were collected from some of the plats and the grain analyzed for its total N. The yields and N content are given in Table 3.

TABLE 3.—*Results of fertilizer experiments for corn on Carrington loam.*

Plat No.	Bushels per acre	N %
1A	59.2	—
1B	60.7	—
2A	58.0	—
2B	61.7	—
3A	57.0	—
3B	51.5	—
4A	49.7	1.47
4B	47.5	1.48
5A	58.5	1.51
5B	49.5	—
6A	49.2	1.47
6B	44.5	1.50
7	51.5	1.54
8	57.2	1.35
9	74.7	1.56
10	68.7	1.52
11	67.2	1.59
12	73.7	1.52
13	64.0	1.64
14	63.0	1.65
15	65.5	—
16	66.5	—

Plats 1B and 6B, which received 100 pounds per acre of nitrate July 3, produced 1.6 bushels per acre less than the adjoining plats 1A and 6A which were untreated. The artificial manure plats, 2A to 5A, produced an average of 55.8 bushels per acre and the adjoining plats 2B to 5B, which had in addition an application of nitrate July 3, produced only 52.5 bushels per acre. Plat 12, the check on the spring plowing, yielded 73.7 bushels per acre which was next to the highest yield in the series. Plat 9 produced the highest yield with 74.7 bushels per acre. Plats 13 and 14, which received 200 pounds per acre of sodium nitrate, yielded nearly 10 bushels per acre less than the adjoining check plat.

No significant difference was noted in the total N content of the grain from the different plats in so far as differences in treatment were concerned.

There is no evidence from these data that sodium nitrate is of any value as a side dressing for corn on Carrington loam which has been kept in a fairly good state of fertility.

SUMMARY

A series of eight plats was established on each of 16 different fields in various parts of the state for the purpose of testing the action of

sodium nitrate applied at the rate of 100 pounds per acre to corn in early, divided, and late applications, with and without superphosphate.

These 16 fields included nine different soil types, mainly on the less productive soils of the state. Due to damaged plats and other circumstances only 11 of the fields were harvested.

Without superphosphate the divided application gave slightly the highest yield, 6.2 bushels per acre increase over the checks as an average for all fields. The early application of nitrate made an average increase of 4 bushels per acre and the late application an average increase of 5 bushels per acre over the checks.

When superphosphate was used in addition to the nitrate, the increase in yield was somewhat less. On some of the fields, superphosphate tended to depress the yield due to dry weather conditions.

Clinton silt loam was most responsive to nitrate fertilizer. The average increased yield for the three fields of this soil type was about 10 bushels per acre from the nitrate fertilizer with very little difference as to the time of application.

The fertilizer applications did not materially influence the nitrogen content of the grain.

One field of Carrington loam was selected for some special studies regarding the effect of sodium nitrate on corn. Sodium nitrate was used on this field in amounts of 100 and 200 pounds per acre in early, late, and divided applications. On some of the plats superphosphate was used at the rate of 120 pounds per acre. On other plats the nitrate was used in connection with different artificial manures and some undecomposed plant residues. There was no evidence that the nitrate fertilizer was of any value on Carrington loam which had been kept in a relatively good state of fertility.

EFFECT OF CLIMATE ON NITROGEN CONTENT OF MAIZE, BARLEY, AND RED CLOVER[1]

E. J. DELWICHE AND W. E. TOTTINGHAM[2]

The purpose of this investigation was to ascertain what differences in chemical composition of crops, if any, are due to weather and climate. The experiment stations at Ashland and Madison, Wisconsin, were chosen as sites for growing the crops in question. The climatic conditions at these two points, while not radically different, differ quite markedly with regard to temperature, length of season, precipitation, and number of clear days.

The difference in latitude between the two points is 3 degrees and 35 minutes, that of altitude 326 feet. These differences, together with the influence of Lake Superior, a large body of water whose waters are always cool, profoundly affect the climate, as will be noted from Tables 1, 2, and 3 for the 10-year period of 1918 to 1927, inclusive. The length of time between killing frost at Ashland averaged 111.3 days and at Madison 168.9 days, a difference of over 57 days. For the growing season, April to September, there is a difference of over 6 degrees F in favor of Madison. Rainfall for the growing season is nearly 3 inches greater at Madison, but as a result of decidedly higher average temperature at the latter place, with consequent greater evaporation, the usable rainfall for crop production at Ashland is probably as great as at Madison. The total number of clear days at the Ashland station averages 142.4 days, as compared with only 95 days at Madison.

The greater number of daylight hours for the summer season, too, should have some influence on the development of crops and quite possibly on the nitrogen-carbohydrate ratio. Taking into consideration the climatic factors mentioned, there appear to be grounds for believing that considerable differences in chemical composition may exist in plants grown at two different points as widely separated as Ashland and Madison. Whether the claim often made by stockmen, that northern pastures, hays, and grains have a greater nutritive value is justified remains to be proved experimentally.

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[1] Contribution from the Departments of Agronomy and of Agricultural Chemistry, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Received for publication January 25, 1930.

[2] Professor of Agronomy and Associate Professor of Agricultural Chemistry, respectively.

TABLE I.—*Climatological data, Ashland, 1918 to 1927, inclusive.**

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	10-yea averag
Killing frost, last in spring	June 23	May 18	May 15	June 4	May 14	May 23	June 7	May 26	June 19	June 14	
Killing frost, first in autumn	Sept. 10	Sept. 26	Sept. 30	Sept. 26	Sept. 14	Sept. 14	Sept. 10	Sept. 21	Sept. 13	Oct. 7	
Length of season, days	79	131	138	114	123	114	97	118	86	115	111.3
Clear, days	167	147	159	149	141	153	142	135	111	120	
Precipitation, inches:											
April	1.91	3.18	2.63	2.30	2.84	1.01	5.54	0.89	0.99	1.35	
May	3.99	1.16	2.32	2.08	2.22	1.56	4.38	0.57	3.51	4.27	
June	1.17	5.98	6.61	3.06	3.85	3.24	1.94	2.99	2.83	3.02	
July	2.73	3.76	5.94	5.70	2.82	5.12	3.66	2.49	2.03	2.89	
Aug	2.63	1.93	3.09	1.97	1.98	1.88	6.68	1.82	3.74	1.10	
Sept	1.40	1.14	1.73	3.32	1.76	2.04	3.35	4.61	7.10	2.09	
Total, April to Sept., inc.	13.83	16.01	22.32	18.43	15.47	14.85	25.55	13.57	20.20	14.72	17.5
Annual precipitation, inches	20.70	27.30	32.90	25.31	26.37	22.13	31.26	17.64	33.01	26.88	
Mean temperature, °F:											
April	35.8	42.0	32.0	44.1	39.6	38.5	38.6	42.7	37.7	39.8	
May	51.6	51.3	51.6	53.0	54.4	49.7	45.5	49.5	50.8	46.0	
June	59.3	64.2	60.1	66.3	62.9	63.8	56.8	62.0	58.4	59.0	
July	65.0	68.0	64.6	72.8	64.8	66.0	63.8	66.4	64.6	63.5	
Aug	65.0	66.7	62.8	63.7	65.4	60.8	62.2	68.4	64.6	59.6	
Sept	50.3	58.4	59.7	59.4	59.2	56.1	53.0	56.7	52.9	59.6	
Average mean temperature, April to Sept., inc.	54.8	58.4	55.1	59.7	57.9	55.8	53.8	57.6	55.0	54.6	56.2
Annual mean temperature, °F	40.2	41.0	40.3	43.3	41.0	40.4	38.4	40.8	38.8	39.2	

*Ashland branch station, elevation 648 feet, latitude 46° 35′.

TABLE 2.—*Climatological data, Madison, 1918 to 1927, inclusive.**

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	10-year average
Killing frost, last in spring	Apr. 25	Apr. 25	May 14	May 15	Apr. 21	May 13	Apr. 20	May 25	Apr. 26	Apr. 23	
Killing frost, first in autumn	Nov. 2	Oct. 17	Oct. 29	Oct. 8	Oct. 17	Oct. 21	Oct. 22	Oct. 10	Sept. 26	Nov. 2	
Length of season, days	191	175	168	146	179	161	185	138	153	193	168.9
Clear, days	100	90	97	69	106	94	96	100	92	106	
Precipitation, inches:											
April	2.63	2.90	3.43	5.16	3.39	2.59	3.25	1.69	1.49	3.39	
May	4.87	3.55	3.51	5.13	4.16	1.90	1.46	0.38	3.75	6.85	
June	1.84	3.35	5.62	3.52	3.17	3.05	4.13	6.05	2.16	2.17	
July	2.33	3.96	1.39	2.46	6.09	2.28	5.01	3.30	3.26	1.97	
Aug	2.03	0.89	2.61	3.97	1.33	5.59	7.23	2.31	1.12	0.46	
Sept	1.52	6.83	1.12	7.90	2.34	4.36	2.87	4.50	6.54	6.22	
Total, April to Sept., inc	15.22	21.48	16.68	23.14	20.48	19.77	23.95	18.23	18.32	21.06	20.33
Annual precipitation, inches	27.27	35.16	27.16	38.56	32.04	31.01	32.28	26.13	30.33	33.19	
Mean temperature, °F:											
April	41.6	45.8	40.4	50.6	45.8	44.0	45.2	51.5	41.6	45.0	
May	61.0	55.2	56.6	60.4	63.6	57.0	51.2	54.4	58.2	54.3	
June	65.9	71.2	69.0	72.2	68.6	71.2	63.8	67.9	63.0	63.6	
July	70.3	74.8	69.1	78.1	69.6	74.2	68.3	70.7	71.0	70.4	
Aug	72.6	69.0	68.8	70.0	71.2	67.9	68.2	70.6	70.6	66.4	
Sept	55.9	64.2	65.5	66.0	65.1	61.7	56.8	65.9	60.5	64.8	
Average mean temperature April to Sept., inc	61.2	63.4	61.6	66.2	64.0	62.7	58.9	63.5	60.8	60.8	62.3
Annual mean temperature, °F	46.2	46.4	45.8	49.5	53.9	46.4	43.7	45.9	44.6	46.4	

*Madison, elevation 974 feet; latitude 43°.

TABLE 3.—*Summary of climatological data, Ashland and Madison, Wis.*

	Ashland	Madison	Ashland (departure)
Latitude	46°35′	43°	+3°35′
Elevation, feet	648	974	—326
Length of season, days	111.3	168.9	—57.6
Number of clear days	142.4	95.0	+47.4
Precipitation, Apr. to Sept	17.5	20.33	— 2.8
Precipitation, annual	26.35	31.26	— 4.9
Aver. mean temperature, Apr. to Sept	56.2°	62.3°	— 6.1°
Aver. mean temperature, annual	40.34°	46.88°	— 6.54°

PREVIOUS WORK

The literature in this field is rather scanty. Mention may be made of the work of LeClerc (3)[3] and of Mangels (4) who found high protein content of wheat associated with hot, dry climates. Wiley (8) found lower temperatures conducive to storage of sucrose in the root of the sugar beet. Bushnell (1) found a similar situation with reference to the supply of starch for development of tubers in the potato. The earlier work of Richardson (5) disclosed remarkable uniformity of composition in maize grain with varying climatic conditions. By use of chambers for the control of environment, the junior writer (6) found that clover tops and the grain of buckwheat and wheat contain greater percentages of nitrogen at higher temperatures.

With reference to the response of legumes, the results of Jones and Tisdale (2) are of particular interest. They found soil temperatures somewhat above 20° C optimal for numbers and sizes of root nodules on clover. In the case of the soybean, larger nodules in this temperature range were accompanied by increased nitrogen content of the plant tops.

SOIL CONDITIONS

The soils of plats utilized at Ashland and Madison do not differ markedly from a chemical standpoint, except for lime content (Table 4). In order to bring the two to approximately the same levels and to provide ample supplies of plant food elements, lime was applied regularly at the rate of 1,000 pounds of limestone per acre to the barley and clover sowing. At first a light dressing of manure was added to the corn crops supplemented by the addition of a standard commercial fertilizer applied in the hill. This was early replaced by an application of a 3–8–10 fertilizer to corn. In 1923, all plats received 240 pounds of rock phosphate per acre. In all cases the second crop of clover was plowed under for the corn crop. Determinations made in 1928 showed a lime requirement of 1 ton for Madison and 3 tons for Ashland, 1.70 and 1.11% C, and 0.17 compared with 0.11% N, respectively. Clover grows well at both stations.

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[3] Reference by number is to "Literature Cited," p. 688.

TABLE 4.—*Composition of soils at Madison and Ashland, Wis.*

	Madison (Miami silt loam)	Ashland (Superior red clay)
	%	%
C	1.45	2.00
N	0.12	0.15
SiO_2	78.36	73.01
TiO_2	0.68	0.64
Al_2O_3	8.20	9.54
Fe_2O_3	2.36	3.16
Mn O	0.20	0.11
V_2O_5	0.11	0.12
Ca O	1.13	0.97
Ba O	0.07	0.09
Mg O	0.66	0.11
K_2O	2.26	2.91
Na_2O	1.30	1.20
P_2O_5	0.16	0.22
SO_3	0.07	0.05
Total acidity, lime equivalent per acre	6.3 tons	13.7 tons
Active acidity, lime equivalent per acre	2.1 tons	4.8 tons

From a physical standpoint the difference between the two stations is quite marked, the Ashland soil being a heavy red clay quite retentive of water, while that at Madison is a brown silt loam of fine texture which can be designated as a good corn soil. Open furrows were provided to facilitate the more rapid removal of surplus surface water. At Ashland corn does not grow very thriftily and only the very earliest kinds mature except in the most favorable seasons.

PLAN OF EXPERIMENT

Crops were grown in a rotation of corn, barley, and clover, each crop being represented each year. Plats (1/80 acre) were 1 rod wide and 2 rods long and were separated by a 3-foot alley. Seed for both stations was from a common source, the corn being a very early flint variety known as Chippewa. It was selected because of its earliness to meet the requirements for Ashland. Oderbrucker barley, a six-rowed kind, was used. Red clover seed out of the same lot was sown at both stations. Planting and harvesting were done at about optimum dates for the two locations.

At first it was planned to make detailed chemical determinations of all the crops, but lack of time prevented continuing on this scale so that only total N determinations were made. General experience indicates that the total available carbohydrates (sugars, starches, and hemi-cellulose) may be expected to vary inversely as the crude protein content. Table 5 gives the results. No analyses were made for barley in 1920, for red clover in 1919 and 1920, or for corn in 1924 because of crop failure due to frost or drought. In order to show departures in composition, the data of Table 5 are summarized in Table 6.

TABLE 5.—*Crude protein content of crops, Ashland and Madison climatic plats.*

	Maize %	Barley %	Clover %
1918			
Ashland	10.0	—	—
Madison	10.0	—	—
1919			
Ashland	12.5	16.2	—
Madison	11.9	15.0	—
1920			
Ashland	11.9	lost	—
Madison	9.4	12.5	—
1921			
Ashland	11.3	13.3	11.1
Madison	9.6	15.9	13.7
1922			
Ashland	11.1	10.5	12.5
Madison	9.9	11.6	15.6
1923			
Ashland	10.6	13.5	14.0
Madison	11.6	14.1	16.3
1924			
Ashland	Frost killed	15.6	13.8
Madison	—	13.1	15.6
1925			
Ashland	11.2	13.7	13.8
Madison	11.7	12.0	14.4
1926			
Ashland	12.6	15.9	16.1
Madison	13.8	13.6	15.2

TABLE 6.—*Summary of average crude protein content of crops at Ashland and Madison with departure in the former case.*

	Maize (8 crops) %	Barley (7 crops) %	Clover (6 crops) %
Ashland	11.4	14.1	13.6
Madison	11.0	13.6	15.1
Difference	+ 0.4	+ 0.5	— 1.5
Ashland departure as % of Madison analyses	+ 3.6	+ 3.7	—10.0

DISCUSSION OF RESULTS

CORN

An average of eight crops gave 3.6% greater content of protein in corn at Ashland than at Madison. In view of the fact that the composition of the corn kernel is generally considered very stable, the difference is noteworthy.

The shortness of the growing season at Ashland, with longer days and less cloudiness than at Madison, may be contributing factors to this difference. In fact, the long, clear, sunshiny days by favoring photosynthesis ought to decrease the percentage of protein in tissues and thus offset, in part, the shortness of season. Again, the short growing season with rapidly shortening days in late August and early September may be the dominant factor by hastening maturity and thus suppressing the full accumulative expression of carbohydrate metabolism.

BARLEY

This crop shows a 3.7% increase in protein at Ashland. The response to climatic difference between the two stations is like that of corn.

CLOVER

The lower percentage of protein in clover at Ashland as compared to Madison is very marked. The Madison environment evidently favors a higher protein content. As a possible explanation, the fact of greater optimum weather conditions, such as greater insolation and relatively low temperature, for starch formation as existing at Ashland might be supposed to result in producing more carbohydrates relative to protein than at Madison. The other possibility is that cooler soil conditions in early spring have the effect of retarding nitrogen fixation by symbiotic action.

According to Jones and Tisdale (2), the greater content of protein in the Madison clover may be due to increased development of root nodules which condition, according to these workers, results from increased temperatures. In their work and elsewhere, one finds evidence of correlation between nodule development and protein content of the plant. The difference in temperature for the growing season, averaging as it does about 6 degrees F, thus appears sufficient to effect the results herebefore discussed.

Thus, the factor of difference in length of season as affecting starch formation, on the one hand, and that of soil temperature as affecting symbiotic nitrogen fixation in the clover, on the other, probably are jointly responsible for the difference in protein content revealed by a chemical analysis of the clover crop.

CONCLUSIONS

1. The contention frequently made by practical men that crops growing in northerly latitudes have a greater value as feed because of a higher protein content finds little support in these experiments.

On the contrary, in the case of clover, the content of protein in the northern Wisconsin grown crop is less than in that grown in southern Wisconsin.

2. In the case of barley and of corn, the protein content is greater in the northern grown crops. Yet, from the standpoint of feed value, the difference is hardly sufficient to have practical value.

3. Judging from these tests, hays and grains of the same varieties when cut at the same period of maturity in both northern and southern Wisconsin have little difference in feeding value. Longer trials may confirm an apparently greater content of protein, as a rule, in southern grown clover.

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SIZE OF PLAT AND NUMBER OF REPLICATIONS IN FIELD EXPERIMENTS WITH COTTON[1]

L. L. Ligon[2]

In varietal and other experiments with cotton, as with farm crops in general, the question of what size plat and the number of replications to be used to obtain reliable and accurate results is of great importance. The nature of the crop and the great amount of labor necessary in obtaining yield data make it desirable to have as small a plat and as few replications as possible. A great deal has been done in determining the size of plats and numbers of replications for small grains, corn, and other crops, but particularly the small grains. For a comprehensive review of this subject the reader is referred to "Breeding Crop Plants," by Hayes and Garber (1).[3] The writer has found nothing, however, in regard to cotton.

The object of the study reported in this paper is to determine the minimum size of plat and number of replications consistent with accuracy for cotton experiments. At the Oklahoma Agricultural Experiment Station previous to the season of 1926 experiments with cotton, excepting varietal tests, have been with one-tenth to one-fifteenth acre plats replicated once. Varietal tests have been mostly single rows with no replications. In this test, check plats were included every third or fourth row.

EXPERIMENTAL RESULTS

It is realized that an adequate study of this problem requires the laying out of plats definitely for this purpose. Frequently, however, considerable information can be obtained from the yield data of experiments conducted primarily for other purposes. The data for this study were taken from plats in the cultural test for the season of 1925 and from the variety tests of 1926 and 1927.

The plats were harvested in such a manner as to permit the use of the data in studying the value of various sized plats and numbers of replications.

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[1] Contribution from the Department of Field Crops and Soils, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Received for publication January 27, 1930.

[2] Associate Agronomist in charge of cotton breeding. The author desires to express his appreciation to Dr. Fred Griffee, Biologist, Maine Agricultural Experiment Station, formerly Plant Breeder, Oklahoma Experiment Station, for his valuable advice and assistance in preparing this paper.

[3] Reference by number is to "Literature Cited," p. 699.

TABLE 1.—*Actual yield in pounds of seed cotton of 100-foot plats in 1925.*

	Series											
	A			B			C			Total yield in 5-row plats		
Plat No.	Row 3	Rows 2–4	Rows 1–5	Row 3	Rows 2–4	Rows 1–5	Row 3	Rows 2–4	Rows 1–5	A	B	C
1	1.50	2.75	3.00	2.50	4.00	4.50	1.66	2.22	3.33	7.3	11.0	7.2
2	6.25	11.00	10.00	6.50	11.00	11.00	8.33	12.77	13.33	27.3	28.5	34.4
3	4.50	10.75	9.50	7.00	15.00	12.50	6.66	14.44	11.66	24.8	34.5	32.8
4	5.00	9.50	11.00	7.50	12.00	14.50	7.22	11.11	13.33	25.5	33.5	32.6
5	4.50	9.25	8.75	4.00	11.00	11.00	4.44	13.33	10.55	22.6	26.0	28.3
6	5.75	9.00	9.50	5.00	9.00	10.00	6.66	13.33	16.66	24.3	24.0	36.7
7	4.50	10.75	9.00	5.50	12.00	9.00	4.99	13.33	9.99	24.3	26.5	28.3
8	4.75	11.00	11.00	6.50	11.00	11.00	6.66	16.66	16.66	25.8	28.5	40.1
9	6.25	11.75	12.50	5.50	12.50	11.50	5.55	13.33	13.33	30.6	29.5	32.2
10	6.25	11.00	11.00	5.50	13.00	12.50	8.33	16.11	14.99	28.3	31.0	39.4
11	5.25	11.25	11.00	7.50	10.50	9.50	6.66	16.66	11.11	27.6	27.5	34.5
12	7.25	12.00	10.50	9.00	14.00	14.00	9.44	15.55	15.55	29.8	37.0	40.6
13	1.00	2.50	3.75	2.50	4.00	5.00	1.66	4.44	6.66	7.3	11.5	12.8
14	7.00	11.75	11.00	6.50	13.00	14.50	8.88	12.22	13.33	29.8	34.0	34.4
15	7.00	12.00	11.50	6.00	11.00	9.00	8.88	16.66	13.33	30.5	26.0	38.9
16	5.50	11.00	13.25	5.00	10.00	11.50	7.22	14.99	14.99	29.8	26.5	37.2
17	6.00	11.75	11.50	5.00	11.50	12.00	6.93	13.33	12.22	29.3	28.5	32.4
18	6.75	12.00	10.25	8.00	14.00	14.00	9.44	14.99	12.77	29.1	36.0	37.2
19	6.00	13.50	14.00	8.00	11.50	12.00	8.33	13.88	13.88	33.5	31.5	36.1
20	9.00	13.00	14.00	6.00	14.50	12.00	7.22	16.66	14.44	35.0	32.5	38.3
21	4.50	8.00	10.88	8.00	15.00	13.00	4.99	14.44	14.44	23.4	36.5	33.8
22	6.50	10.00	8.50	6.00	12.50	13.00	6.66	12.77	12.77	25.0	31.5	32.3
23	6.00	9.00	8.50	5.50	13.00	13.00	6.66	12.77	12.22	23.5	31.0	31.7
24	5.00	8.30	11.00	7.50	10.00	9.25	7.22	11.66	9.99	24.3	26.8	28.9

TABLE 2.—*Probable error and standard deviation in % of mean, 1925.*

	Single row			Two rows			Three rows			Five rows		
100-foot rows:	A	B	C	A	B	C	A	B	C	A	B	C
Standard deviation	15.98	13.90	12.69	11.23	11.44	12.78	11.64	10.41	10.26	11.52	10.70	11.19
P. E. of single determination	10.78	9.38	8.56	7.57	7.72	8.62	7.85	7.02	6.92	7.77	7.22	7.55
P. E. in % for two systematic plats	7.62	6.63	6.05	5.35	5.46	6.10	5.55	4.96	4.89	5.49	5.11	5.34
200-foot rows:	A+B		B+C	A+B		B+C	A+B		B+C	A+B		B+C
Standard deviation	10.30		11.29	8.75		8.35	8.66		9.86	7.45		8.50
P. E. of single determination	6.95		7.95	5.90		5.63	5.84		6.65	5.03		5.73
P. E. in % of two systematic plats	4.91		5.62	4.17		3.98	4.13		4.70	3.56		4.05
300-foot rows:		A+B+C			A+B+C			A+B+C			A+B+C	
Standard deviation		10.60			7.69			7.76			7.63	
P. E. of single determination		7.15			5.19			5.23			5.15	
P. E. in % of two systematic plats		5.06			3.67			3.70			3.64	

SEASON OF 1925

The field work with cotton in 1925 included a cultural test embracing 11 different methods of cultivation and no cultivation. There were two systematically distributed plats of each treatment. The plats were five rows in width and 300 feet in length, or slightly over one-eighth of an acre in size. For the purpose of this study each plat was harvested in three smaller plats 100 feet in length. Also, rows 1 and 5 were harvested together, rows 2 and 4 were harvested as one, and the center row was harvested separately. This method of harvesting provided 72 plats 100 feet in length and 1, 2, 3, and 5 rows in width. It also provided data on plats 200 and 300 feet in length with the various row widths. The yield data are given in Table 1.

Standard deviations and probable errors were calculated by the "deviation from the mean" method as outlined by Hayes (2). The constants obtained for the various sized plats are given in Table 2 for a single determination and for two systematically distributed plats. The results indicate that for single row plats a 200-foot length is more reliable than a 100-foot length, but that there is no advantage gained by increasing the length to 300 feet. The same may be said for plats 2, 3, and 5 rows in width. With 2-, 3-, and 5-row plats a length of 100 feet seems as desirable as any length greater than that and particularly for the 5-row plats.

TABLE 3.—*Correlations of yields expressed in % of various size plats one, two, and three apart, 1925.*

	r	σr
100-foot rows:		
Plats one apart	0.4031	0.1008
Plats two apart	0.5974	0.0792
Plats three apart	0.5381	0.0895
300-foot rows:		
Plats one apart	0.6759	0.1133
Plats two apart	0.4560	0.1689
Plats three apart	0.1326	0.2144

With the yields of the various plats given in percentage, it is possible to obtain an index of soil variability by means of the correlation coefficients for adjacent plats and for plats of varying distances apart by the method devised by Hayes (1). Computations were made for plats of 100 feet and 300 feet in length for adjacent plats and for plats two and three plats apart. The correlation coefficients and their standard deviations are given in Table 3. The correlation coefficients for 100-foot plats are practically the same for all three calculations. For plats 300 feet in length, however, there is a marked and progressive reduction in the size of the correlation coefficients directly in proportion to the distance between plats. The inference is that soil variation is extant over relatively large areas across the field and that perhaps the greatest variation is to be found in the lengthwise direction of the rows.

SEASON OF 1926

The variety test for 1926 consisted of three plats each of 37 varieties systematically replicated with a check plat every fourth plat. The plats were three rows in width and 100 feet in length. Each row of each plat was harvested separately. The actual yields in pounds of seed cotton are given in Table 4. The standard deviations and probable errors were calculated by the "deviation from the mean" method.

Table 4.—*Actual yield of seed cotton of cotton plats by rows in 1926, check plats omitted.*

	Series								
Plat	A			B			C		
No.	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3
1	4.6	4.5	4.4	—	—	—	—	—	—
2	4.8	4.3	4.3	4.3	4.2	3,5	3.9	4.3	4.2
3	4.0	4.4	4.9	4.2	4.3	4.7	3.5	4.1	3.6
4	3.3	4.1	3.7	4.2	4.5	5.4	3.8	4.2	5.1
6	4.3	4.1	4.5	3.8	5.1	5.5	3.8	4.0	4.9
7	3.9	3.9	4.5	5.0	5.7	4.2	3.8	5.4	5.1
8	5.2	4.6	4.7	5.5	6.0	5.5	5.7	4.9	5.2
10	3.8	3.2	4.6	5.2	4.9	5.3	3.2	3.3	3.9
11	4.6	4.6	4.9	5.7	5.3	4.7	4.7	5.0	4.9
12	4.8	3.7	5.8	5.8	6.2	6.6	3.6	3.3	4.4
14	4.9	5.0	5.3	4.3	4.0	5.3	3.8	4.2	5.8
15	4.7	5.2	5.3	4.8	6.6	6.2	4.4	3.5	3.8
16	6.8	5.5	6.4	7.2	5.4	5.2	4.0	3.7	3.9
18	5.3	5.2	4.6	4.4	3.9	4.6	4.6	5.1	4.5
19	4.8	4.8	4.0	5.4	6.7	7.6	4.6	5.1	4.8
20	3.9	7.1	6.0	6.6	6.1	7.0	4.5	5.1	5.0
22	6.6	7.4	4.9	5.9	5.8	5.7	5.3	5.0	4.8
23	5.2	5.9	7.0	5.0	5.7	6.2	5.2	5.6	6.6
24	4.4	4.3	5.7	4.9	5.0	3.3	6.1	4.9	5.7
26	5.6	5.8	5.6	4.0	5.2	5.0	4.5	5.9	4.7
27	5.2	5.8	5.9	3.3	5.2	5.4	4.6	4.8	5.1
28	6.7	6.2	6.8	4.9	4.7	4.9	5.7	4.5	4.8
30	5.4	5.1	5.1	4.4	5.2	4.7	4.4	4.4	5.3
31	5.9	5.9	6.1	3.5	4.2	4.8	5.2	4.5	4.1
32	4.5	5.1	4.8	7.9	7.5	5.8	7.0	5.0	5.5
34	4.9	4.1	4.6	5.5	4.7	4.5	3.9	4.8	3.8
35	5.0	4.5	5.0	3.9	4.0	6.0	5.3	5.7	6.2
36	4.0	4.2	4.8	4.5	4.1	5.1	5.1	5.0	6.6
38	4.2	4.8	3.9	5.1	4.6	5.0	5.0	5.1	5.4
39	4.4	4.6	4.7	3.1	4.4	4.8	4.3	5.0	4.9
40	4.5	3.9	5.1	4.9	4.2	5.9	5.2	3.7	4.1
42	5.1	5.9	5.3	4.3	4.9	4.3	4.6	5.1	5.1
43	5.0	5.3	4.9	3.6	4.6	3.8	3.8	4.6	5.4
44	5.3	5.2	4.5	3.9	3.6	4.2	5.1	5.1	5.4
46	5.6	5.1	4.7	4.6	3.6	3.7	5.6	4.7	4.9
47	5.3	5.8	4.4	4.5	4.0	4.2	4.2	4.4	5.2
48	5.4	5.0	4.8	4.5	5.3	6.0	5.2	5.0	5.7
50	4.3	3.5	4.1	4.2	4.7	4.9	4.7	4.6	3.5
51	3.7	2.4	4.0	4.6	4.9	4.6	4.2	4.4	4.2
52	4.3	3.1	4.1	5.6	3.9	3.9	4.1	2.5	4.4
54	2.4	2.1	2.8	3.7	2.9	3.3	4.5	4.1	2.9
55	4.6	4.1	3.9	3.2	3.6	4.9	3.6	3.5	4.6
56	3.8	4.6	3.9	3.9	2.8	5.1	4.1	3.4	4.1

The data from these calculations are given in Table 5. The variation appears slightly greater for the central rows than for either of the side rows, although the differences are not very large. This fact might justify one in assuming that more reliable results would be obtained by the use of three-row plats and the use of the central row alone for yield determinations. The standard deviations and probable errors of three-row plats of different length rows show very little variation.

The constants for the three-row plats show little variation between 100- and 200-foot rows, but there is a slight advantage obtained by increasing the rows to 300 feet. This slight advantage must be disregarded when the amount of land is limited and the soil very variable.

TABLE 5.—*Standard deviation and probable error of different size plats, 1926.*

	Standard deviations		
100-foot rows	Single determination	Three distributed plats	P.E. in % for 3 plats
Single rows:			
Row 1, outside row	12.82	7.40	4.99
Row 2, middle row	16.36	9.44	6.37
Row 3, outside row	13.75	7.94	5.36
Two-row plats:			
Rows 1 and 2	13.60	7.85	5.29
Rows 2 and 3	13.42	7.75	5.23
Rows 1 and 3	11.79	6.81	4.59
Three-row plats:			
Rows 1, 2, and 3	12.48	7.21	4.86

200-foot rows	Standard deviation for single determination	P. E. in % for single determination
Series A+B	12.85	8.67
300-foot rows		
Series A+B+C	10.02	6.76

Correlations were determined for the plats of varying distances apart and for plats of various lengths obtained by adding percentage values from Table 6. The correlation coefficients are given in Table 7. There is a slight reduction in the correlation coefficient for plats three apart in the 100-foot length, although the difference between this value and that for adjacent plats is less than the probable error of the difference. In the case of rows 200 and 300 feet in length the correlations are very high. This situation might be explained by assuming that these larger plats are so situated as to include in each plat the various good and poor spots. In other words, each large plat is a reasonably representative sample of the area represented by three plats in width. A high correlation would be expected under this condition. In fact, if all plats are alike in yielding performance a perfect correlation would exist irrespective of the location of the plats with each other. The fact that the correlations for the shorter length plats are lower than for the longer plats suggests that the greatest variation is lengthwise of the rows if the above assumption is correct.

TABLE 6.—*Yields of seed cotton in 1926 expressed in % of variety average, check plats omitted.*

Plat No.	Series A	B	C	Plat No.	Series A	B	C
1	——	——	——	29	——	——	——
2	86.4	92.3	83.2	30	117.3	104.4	106.8
3	90.6	90.4	81.9	31	114.7	93.3	100.0
4	89.5	100.0	100.0	32	110.8	125.6	111.5
5	——	——	——	33	——	——	——
6	92.1	94.1	92.7	34	108.8	103.5	114.7
7	92.5	94.3	97.9	35	115.1	100.0	104.2
8	93.5	104.9	90.7	36	109.2	95.1	103.1
9	——	——	——	37	——	——	——
10	83.9	100.7	78.2	38	99.2	106.6	100.6
11	104.4	104.0	94.9	39	101.5	97.6	94.6
12	85.1	113.4	86.2	40	95.7	104.1	104.8
13	——	——	——	41	——	——	——
14	106.3	103.8	110.4	42	107.2	89.9	106.4
15	108.6	127.5	92.9	43	96.2	87.0	103.0
16	131.0	114.7	97.5	44	92.6	90.0	102.0
17	——	——	——	45	——	——	——
18	110.2	118.3	109.2	46	100.0	87.6	110.9
19	108.7	118.8	107.4	47	100.7	87.0	102.2
20	117.2	121.0	105.0	48	94.5	88.3	88.7
21	——	——	——	49	——	——	——
22	126.8	112.3	99.3	50	90.2	103.8	90.1
23	130.4	114.1	110.1	51	73.2	89.7	91.4
24	110.8	106.5	103.1	52	73.7	103.1	75.7
25	——	——	——	53	——	——	——
26	120.4	102.1	99.3	54	66.1	80.0	83.9
27	115.8	103.7	96.0	55	76.4	92.9	92.9
28	121.6	104.6	92.1	56	75.9	92.4	79.3
				57	——	——	——

TABLE 7.—*Correlations of yields of various sized plats one, two, and three apart, 1926.*

100-foot rows:	r	σr
Plats one apart.......	0.4362	0.0884
Plats two apart.......	0.6054	0.0704
Plats three apart.....	0.3502	0.1341

	A+B		B+C		A+C	
200-foot rows:	r	σr	r	σr	r	σr
Plats one apart.......	0.8258	0.0601	0.6079	0.1191	0.7760	0.0752
Plats two apart.......	0.7916	0.0719	0.3987	0.1619	0.7903	0.0723
Plats three apart......	0.8437	0.0565	0.6152	0.1219	0.7267	0.0925

300-foot rows, A+B+C:	r	σ
Plats one apart.......	0.7985	0.0685
Plats two apart.........	0.8235	0.0619
Plats three apart......	0.8121	0.0668

SEASON OF 1927

The variety test for the season of 1927 included 48 varieties and strains. Check plats were included at eight-plat intervals. The same general treatment of the data was given as for the previous years. The actual yield data are given in Table 8. The standard deviations and probable errors were calculated, as before, by the "deviation from the mean" method, and are given in Table 9. The center row

TABLE 8.—*Actual yield in seed cotton of cotton plats by rows in 1927, check plats omitted.*

	Series								
Plat	A			B			C		
No.	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3
1.....	5.8	7.6	7.8	—	—	—	—	—	—
2.....	6.0	6.3	7.0	4.8	5.3	5.3	4.5	5.0	5.3
3.....	5.4	4.6	5.8	1.7	3.1	3.8	7.3	6.8	6.5
4.....	1.9	2.7	1.5	10.4	7.3	6.3	5.8	5.4	6.3
5.....	3.5	3.4	2.8	6.8	6.8	6.2	5.0	5.8	4.5
6.....	2.6	3.2	3.8	5.1	6.3	6.6	4.7	4.3	4.5
7.....	2.4	2.8	2.1	7.5	6.1	6.0	8.5	7.9	7.8
8.....	5.3	5.1	4.9	7.7	9.4	7.3	7.8	6.6	7.1
9.....	6.5	5.5	6.1	8.2	7.9	7.5	7.8	6.6	8.8
11.....	8.0	8.0	7.4	8.8	9.3	8.3	9.8	8.8	8.8
12.....	7.8	5.1	5.1	8.8	9.5	10.0	8.8	8.2	9.1
13.....	6.3	6.8	7.3	5.6	4.1	4.9	9.1	8.3	8.8.
14.....	6.5	5.5	5.8	4.4	5.0	4.9	8.0	8.6	8.8
15.....	7.8	7.0	6.5	2.4	3.3	2.3	7.6	8.9	8.6
16.....	4.5	4.5	4.9	4.3	5.2	5.5	7.9	6.1	4.6
17.....	2.0	3.1	2.1	8.3	7.7	7.6	6.0	5.3	9.3
18.....	1.9	2.4	2.0	3.4	4.1	2.8	5.0	4.1	5.1
20.....	2.1	2.7	2.5	6.4	6.2	7.0	5.8	7.4	8.0
21.....	3.3	4.6	3.8	7.0	5.9	5.0	3.2	2.5	4.4
22.....	3.8	3.8	4.4	2.6	3.2	2.5	7.4	6.1	5.5
23.....	4.3	4.2	3.5	4.9	4.5	4.8	5.6	8.6	7.0
24.....	3.1	3.2	2.5	3.4	4.1	4.0	5.8	7.0	7.0
25.....	4.8	6.9	7.0	2.8	2.6	2.8	7.9	7.3	6.2
26.....	5.8	6.0	5.4	4.3	4.8	4.8	7.9	9.3	8.1
27.....	7.5	5.8	6.3	6.3	5.4	5.8	9.0	8.8	9.5
29.....	6.4	7.5	8.0	6.4	7.9	7.4	7.0	9.0	8.3
30.....	7.0	7.2	7.8	3.5	4.1	5.4	8.3	8.7	10.0
31.....	7.8	6.5	8.6	5.3	5.6	6.3	4.5	4.9	5.0
32.....	7.3	7.8	6.5	5.3	5.2	5.0	5.1	5.6	4.8
33.....	7.4	7.1	7.0	6.5	6.7	7.1	1.5	2.8	3.0
34.....	6.3	5.2	4.4	5.0	4.8	4.0	6.5	9.2	6.0
35.....	4.3	5.0	6.1	2.6	3.1	3.5	9.3	9.4	9.9
36.....	4.6	4.1	5.1	2.9	3.1	3.5	4.2	4.5	6.5
38.....	4.4	6.5	6.3	3.5	3.5	4.0	7.8	7.2	6.8
39.....	1.4	3.5	2.4	5.9	6.0	5.8	7.0	6.8	7.1
40.....	7.6	6.0	5.8	4.4	4.8	5.4	3.5	4.4	3.8
41.....	6.5	6.4	7.1	4.8	5.3	4.9	4.3	5.0	5.3
42.....	5.4	7.2	7.2	4.5	4.7	4.5	5.0	4.0	4.4
43.....	7.8	7.3	6.2	8.5	8.2	8.1	4.4	4.1	4.3
44.....	6.9	9.4	8.1	6.3	6.8	7.0	6.3	6.5	5.0
45.....	7.3	9.0	9.3	7.0	7.6	6.5	6.6	6.1	7.5
47.....	8.8	8.1	8.6	8.4	8.9	7.9	9.0	8.4	8.0
48.....	8.8	9.2	4.5	8.9	12.6	9.9	6.4	5.9	7.3
49.....	5.8	6.2	5.8	9.2	7.5	8.4	7.7	7.3	7.5
50.....	5.4	5.1	4.5	9.1	8.1	7.3	7.5	7.5	7.0
51.....	2.3	3.3	2.6	7.8	8.7	9.3	6.9	8.3	7.6
52.....	6.1	5.2	5.5	8.5	8.1	6.7	9.0	7.4	7.1
53.....	9.2	8.2	8.3	8.1	6.8	8.9	4.5	4.8	4.6
54.....	6.5	5.2	5.0	8.4	7.4	7.7	3.9	4.2	4.0

TABLE 9.—*Standard deviation and probable error of different size plats, 1927.*

	σ Single determination	σ Three distributed plats	P. E. in %
100-foot rows			
Single rows:			
Row 1, outside row	17.94	10.36	6.99
Row 2, middle row	14.40	8.31	5.61
Row 3, outside row	16.65	9.61	6.48
Two-row plats:			
Rows 1 and 2	14.79	8.54	5.76
Rows 2 and 3	14.23	8.22	5.54
Rows 1 and 3	15.59	9.00	6.07
Three-row plats:			
Rows 1, 2, 3	14.44	8.34	5.63
		P.E. in % of single determination	
200-foot rows			
Three-row plats:			
Series A+B	11.08	7.47	
300-foot rows			
Series A+B+C	9.36	6.31	

TABLE 10.—*Plat yields of seed cotton in 1927 expressed in % of variety average.*

Plat		Series		Plat		Series	
No.	A	B	C	No.	A	B	C
1	95.5	86.0	134.5	27	——	——	——
2	86.3	89.6	124.1	28	88.7	92.3	97.7
3	70.1	114.5	118.4	29	83.0	77.4	103.9
4	75.8	97.5	108.5	30	92.7	85.9	92.3
5	83.5	93.8	108.0	31	90.8	84.2	104.0
6	77.7	94.2	102.6	32	89.6	94.4	93.6
7	99.7	99.2	109.7	33	82.4	80.7	121.9
8	97.3	92.5	109.0	34	76.5	92.0	111.3
9	——	——	——	35	79.7	101.1	108.6
10	99.6	102.7	110.9	36	——	——	——
11	106.5	109.3	98.5	37	96.1	100.0	107.4
12	102.0	93.6	106.5	38	76.0	106.6	114.8
13	96.2	96.0	106.7	39	93.7	99.3	134.5
14	99.1	101.3	103.7	40	99.0	105.7	113.3
15	81.3	83.7	95.9	41	103.4	114.2	116.5
16	72.0	91.5	103.5	42	101.9	105.5	135.1
17	67.7	72.9	82.6	43	99.2	102.6	115.9
18	——	——	——	44	100.4	99.5	109.1
19	67.3	97.0	119.0	45	——	——	——
20	69.9	98.4	105.2	46	99.6	101.2	108.1
21	81.6	95.4	91.8	47	86.9	118.5	116.2
22	85.1	110.2	104.4	48	113.5	101.2	113.1
23	95.0	99.1	103.4	49	100.7	103.4	119.6
24	91.9	86.2	102.9	50	103.8	107.5	106.0
25	87.2	87.9	102.8	51	95.0	121.2	138.0
26	92.0	93.5	106.7	52	98.8	119.0	139.0
				53	119.3	136.6	130.1
				54	——	——	——

of the three-row plats showed less variability in this season than the outside row, the difference, however, not being very great. Two- and three-row plats apparently were no better than a single row for the 100-foot length rows.

TABLE 11.—*Correlations of yields of various sized three-row plats, one, two, and three apart, 1927.*

95-foot rows	r	σr
Plats one apart	0.7664	0.0368
Plats two apart	0.5023	0.0826
Plats three apart	0.5428	0.0193

200-foot rows	A+B		B+C		A+C	
		σr	r	σr	r	σr
Plats one apart	0.7437	0.0689	0.7047	0.0777	0.8089	0.0533
Plats two apart	0.6258	0.095	0.6577	0.0886	0.5404	0.1106
Plats three apart	0.4465	0.1266	0.3876	0.1344	0.4814	0.1215

300-foot rows A+B+C	r	σr
Plats one apart	0.8075	0.0537
Plats two apart	0.5936	0.1011
Plats three apart	0.5075	0.1174

Correlation coefficients were calculated from percentage yield values (Table 10), as in former seasons, for adjacent plats and plats two and three plats apart. The values are given in Table 11.

Adjacent plats were closely related from the standpoint of yield values in all lengths of plats. There was a slight reduction in the correlation coefficients for plats two and three plats apart for all lengths of plats and a further reduction for the 200- and 300-foot lengths for plats three apart, although the reduction in the latter case is not significant.

Three-row plats with 300-foot rows show less variation for this season than either 100- or 200-foot rows. This reduction can be disregarded in view of the larger number of replications possible when the smaller plats are used.

DISCUSSION

Due to the great amount of labor required in obtaining yield data in the cotton crop, it is desirable to have as small an individual plat as is consistent with accuracy and reliability. It would seem that in cotton field tests in which yield is a factor for consideration that the rows need not be longer than 100 feet. It is quite possible that shorter rows with an increase in the number of replications might be even more desirable. A three-row plat in which the central row only is used for yield data appears to be as desirable as plats with a greater number of rows. In field trials, the experimental error due to soil variation may be expected to run around 5%. Plats of single rows 100 feet in length gave a probable error of 6.05% for one replication in 1925 and probable errors of 6.37% and 5.61% for two replications in the seasons of 1926 and 1927, respectively. It might be well to advise the use of three replications, or four plats of each variety.

However, one should keep in mind the possibility as suggested by Salmon (3) that an added replication results in an increase in the size of the field and a consequent likely increase in the soil variability.

SUMMARY

1. Comparative data were obtained for various sized plats in one and two replications for the seasons of 1925, 1926, and 1927 at Stillwater, Oklahoma.

2. The probable errors for single-row plats 100 feet in length are 6.05% and 7.62% for the season of 1925; 6.37% for the season of 1926; and 5.61% for 1927. In 1925, one replication was used and in 1926 and 1927 two replications.

3. The probable errors for single-row plats 200 feet in length are 4.91% and 5.62% and 5.06% for plats 300 feet in length for the season of 1925. One replication was used

4. The probable errors for three-row plats, 100, 200, and 300 feet in length are 4.86% and 8.67% and 6.76% for the season of 1926. Two replications of 100-foot rows and single determinations for 200- and 300-foot rows were used.

5. The probable errors for three-row plats 100, 200, and 300 feet in length are 5.63%, 7.47%, and 6.3% for the season of 1927 Two replications of 100-foot row plats and single determinations for the 200- and 300-foot plats.

6. Correlations of the yield of plats one, two, and three apart with rows 100 and 300 feet in length were determined for the season of 1925 (Table 3).

7. Correlations of the yields of plats one, two, and three apart with rows 100, 200, and 300 feet long were determined for the seasons of 1926 and 1927 (Tables 7 and 11).

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GENETIC RELATIONS OF COTYLEDON COLOR TYPES OF SOYBEANS[1]

Collins Veatch and C. M. Woodworth[2]

The cotyledons of soybeans (*Soja max* Piper) are either yellow or green when mature. The yellow color is dependent upon two duplicate factors, D_1 and D_2, either one or both of which may produce the yellow color. However, there are two types of green, namely, maternal and genetic, distinguished by their appearance and by their mode of inheritance. The maternal green is, as a rule, a lighter or more yellowish green than the genetic type. When used as the female parent in crosses with yellow cotyledon varieties the hybrids breed true for the green color of cotyledon shown by the maternal parent. Hence, this type of green is said to be maternally inherited. The genetic green, on the other hand, in reciprocal crosses with yellow types produces hybrids that segregate for cotyledon color, producing again the parental types in definite ratios.

Maternal inheritance of cotyledon color in the soybean was reported by Terao (3)[3] in 1918. He considered both green and yellow to be maternally inherited. In 1921, Woodworth (4) reported segregation in cotyledon color in the progeny of his soybean crosses involving yellow and green cotyledon. Piper and Morse (2), in 1923, reported a few artificial crosses showing maternal inheritance of cotyledon color. They also gave data on natural hybrids that segregated for green and yellow cotyledons. Owen (1), in 1927, reported both genetic and maternal greens in his crosses. The maternal green type produced no effect on the cotyledons of the progeny when used as the pollen parent in crosses on yellow cotyledon types, although all the other characters involved in the crosses behaved genetically as expected.

Three strains of the maternal green cotyledon type of soybeans were used in our crosses (Tables 1 and 2). The strain designated as Progeny 1257 was sent to us by Dr. Terao and is one of the types used in his crosses when he found maternal inheritance. The Medium Green or Guelph is a selection from Medium Green. The 435B is a selection from the progeny of a cross between Medium Green x a dominant glabrous type. The 435B selection is characterized by

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[3] Reference by number is to "Literature Cited," p. 702.

maternal green cotyledons and the dominant glabrous character. There are then only two distinct lines concerned in this report, so far as the maternal green cotyledon is concerned—Progeny 1257 and the Medium Green.

Among the crosses made in the greenhouse in 1927 were two between genetic green ♀ x maternal green ♂. On examination, the cotyledons of these hybrid seeds were found to be yellow, indicating that the maternal green type carried genetic factors for yellow. This was further proved by the segregation in cotyledon color in the progeny. Up to the present time, only three of the F_2 populations have been grown. These F_2's gave ratios indicating a 15:1 relationship between yellow and green cotyledons (Table 1). In these three crosses, the 435B strain was the pollen parent and transmitted the dominant glabrous character to the progeny, thus proving the parentage of the hybrid. We have made 12 other crosses between six lines of genetic greens and three lines of maternal greens, giving a total of 41 seeds (Table 1). All of these hybrid seeds have yellow cotyledons.

TABLE 1.—*Soybean crosses showing maternal green to behave as genetic yellow when used as the pollen parent in crosses with genetic green.*

Genetic green ♀	Maternal green ♂	No. seeds	F_1	F_2 Yellow	F_2 Green	Observed F_2 ratio	Dev.*/P.E.
339	435B	1	Yellow	37	4	9.25:1	1.32
Chimera	435B	1	Yellow	65	5	13.00:1	0.34
412G	435B	2	Yellow	134	11	12.18:1	0.50
Chimera	Med. Green	4	Yellow	—	—	——	——
339	Med. Green	2	Yellow	—	—	——	—
Columbia	Prog. 1257	1	Yellow	—	—	——	——
Columbia	435B	1	Yellow	—	—	——	——
Chrom. Green	Med. Green	1	Yellow	—	—	——	——
Chrom. Green	Prog. 1257	2	Yellow	—	—	——	——
Chrom. Green	435B	2	Yellow	—	—	——	——
Narrow Leaf	Prog. 1257	1	Yellow	—	—	——	——
Narrow Leaf	435B	4	Yellow	—	—	——	——
Narrow Leaf	Med. Green	3	Yellow	—	—	——	——
Black Coat	Med. Green	15	Yellow	—	—	——	——
Black Coat	Prog. 1257	1	Yellow	—	—	——	——
Total		41	All yellow	236	20	11.18:1	0.59

*Based on expected 15:1 ratio.

TABLE 2.—*Soybean crosses showing maternal green to behave as genetic yellow when used as the pollen parent in crosses with yellow.*

Yellow ♀	Maternal green ♂	No. seeds	Cotyledon color F_1	Cotyledon color F_2
Wea	435B	2	Yellow	All yellow
Recess. glab	435B	2	Yellow	All yellow
Dunfield	Prog. 1257	2	Yellow	All yellow
Brown hilum	Prog. 1257	1	Yellow	All yellow
Brown coat	Prog. 1257	4	Yellow	All yellow
Early Manchu	Med. Green	4	Yellow	——
Variegated B	Prog. 1257	2	Yellow	——
Mottled	Prog. 1257	1	Yellow	——
Illini	435B	3	Yellow	——
Total		21		

Further proof that these maternal green strains are genetically yellow is given in Table 2. This table gives the results obtained by crossing yellow ♀ x maternal green ♂. If the maternal green type carries genetic factors for yellow the progeny will breed true for yellow. However, if the maternal green type carries genetic factors for green, green cotyledon beans will segregate in the F_2 and succeeding generations. Five of the nine crosses of yellow ♀ x maternal green ♂ have been grown through the F_2 generation and have all bred true for yellow cotyledons. Hence, the results indicate that the maternal green type carries genetic factors for yellow.

Theoretically, it should be possible to isolate a maternal green type that carries the genetic factors d_1 d_2 for green. A difference has been observed in the intensity of green in the progeny of maternal green ♀ x genetic green ♂, but no ratios have been determined. It should be possible to isolate maternal green strains carrying genetic factors d_1 d_2 for green by selecting the darker green segregates from the progeny of such crosses. These selections could then be tested by back crossing as the male parent on the genetic green type. The desired type would give green cotyledons in the F_1 instead of yellow.

The analysis which has been made of the maternal green soybean has shown that it behaves as a genetic yellow. The color of the cotyledon is mainly determined by the cytoplasm of the cell, but the factors for yellow carried on the chromosome seem to exert some influence since the cotyledons are lighter green than the cotyledons of the genetic green type. We usually think of the nucleus rather than the cytoplasm as dominating the activities of the cell, but the case here described appears to be an exception to the rule.

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THE EFFECT OF ORGANIC MATTER UPON SEVERAL PHYSICAL PROPERTIES OF SOILS[1]

L. D. BAVER[2]

Organic matter constitutes a portion of the colloidal content of surface soils. Since colloidal material is responsible for most of the physico-chemical phenomena observed in soils, it is evident that organic matter plays an important rôle in the physical properties of surface soils.

The absorptive capacity of soils for cations is increased considerably by the presence of organic matter. Kerr (3)[3] found that the absorptive capacity due to organic matter varied from 7% to 28% in the three soils that he studied. It has been observed that organic matter has a decided effect on the plasticity of soils as measured by the Atterberg plasticity constants (5). Burr and Russell (1) found that depletion of the organic content of the soil lowered the scouring point, decreased the plastic range, and increased the toughness and solidity. Addition of organic material increased the stability of the soil granules and increased porosity. Robinson (4) maintains that a mechanical analysis of a soil containing much organic matter does not give a true indication as to the prime particle structure of the soil. He advocates oxidation of the organic matter by a H_2O_2 treatment in order to secure correct results.

It is the purpose of this paper to report the results of a study of the relation of organic matter to the absorptive capacity for cations, water absorption, plasticity constants, and mechanical analyses of soils.

EXPERIMENTAL

Four soils with widely different physical characteristics were chosen for this study. The soils were air-dried and crushed to pass a 2-mm screen. Four hundred grams of each of these soils were oxidized by a H_2O_2 treatment. This was accomplished by placing 50 grams of soil and 150 cc of a 3% solution of H_2O_2 in a 1-liter beaker on a water bath at a temperature of 55° C. The soil suspension was frequently stirred in order to hasten the oxidation. When frothing and the escaping of gas had ceased, 10 cc of 3% H_2O_2 were added to the beakers. This process was continued until no further oxidation appeared to take place. About two days were required to complete the oxidation. The soils were filtered with suction on a Buchner funnel and thoroughly washed with distilled water. They were air-dried and crushed to pass through a 2-mm screen.

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[3] Reference by number is to "Literature Cited," p. 708.

The C contents of the original and oxidized soils were determined by the chromic acid method of Schollenberger (6). Table 1 gives the organic matter in percentage of C of these soils before and after oxidation with H_2O_2. Oxidation of the organic matter at this temperature with a 3% H_2O_2 solution was not complete, only about three-fourths of the organic material having been oxidized.

TABLE 1.—*Carbon content of the soil as affected by a hydrogen peroxide treatment.*

Soil	Carbon Original soil %	 Oxidized soil %	Organic matter oxidized %
Huntington fine sandy loam	1.5	0.65	56.7
Chippewa silty clay loam	3.5	0.40	88.6
Toledo silty clay	7.0	2.10	70.0
Blanchester silt loam	1.3	0.15	88.4

RELATION OF ORGANIC MATTER TO ABSORPTIVE CAPACITY OF SOIL FOR CATIONS

In order to determine the effect of organic matter upon the absorptive capacity of the soil exchange complex, 100 grams of soil, before and after oxidation, were leached with a neutral solution of ammonium acetate. The milligrams of ammonia absorbed per 100 grams of soil were determined, this value indicating the absorptive capacity of the soil in terms of milligram-equivalents. This method of measuring the exchange capacity of a soil is described in detail by Courey and Schollenberger (2). The results given in Table 2 show that organic matter constitutes a large portion of the exchange

TABLE 2.—*The relation of organic matter to the absorptive capacity of the soil for cations and for moisture.*

Soil	Absorptive capacity for cations Original soil mg.equiv.	 Oxidized soil mg.equiv.	Absorptive capacity due to organic matter %	Moisture absorption Original soil %	 Oxidized soil %	Absorption due to organic matter %
Huntington fine sandy loam	9.91	6.96	29.76	3.35	2.55	23.88
Chippewa silty clay loam	28.32	13.17	53.53	7.81	5.80	25.73
Toledo silty clay	46.90	18.65	60.25	13.24	8.00	39.50
Blanchester silt loam	14.85	9.40	36.70	4.52	3.53	20.00

complex in these soils. The absorptive capacity due to organic matter varied from 30% to 60%. This indicates that the absorptive capacity of surface soils is controlled to a large extent by the organic material present.

RELATION OF ORGANIC MATTER TO WATER ABSORPTION BY SOILS

Organic matter possesses a fairly high absorptive capacity for water. Data in Table 2 show the effect of removing the organic material in these soils upon the absorption of water from a 3.3% H_2SO_4 solution. Absorption of water due to organic matter varied from 20% to 40% in these four soils.

EFFECT OF ORGANIC MATTER UPON PLASTICITY OF SOILS

In studying the Atterberg plasticity constants of different soil profiles, it was observed that the upper and lower plastic limits of the surface horizons were always fairly high on the moisture scale when compared with the other horizons of the profile. There generally was a good correlation between plasticity and clay content with the exception of these surface soils. The presence of organic matter with a relatively high water absorptive capacity undoubtedly was responsible for these high plastic limits. Table 3 and Fig. 1 show the plasticity limits of four widely different soils before and after oxidation of the organic matter. It is very evident from these results that organic matter causes a raising of both the upper and lower plastic limits. Oxidation of the organic matter has produced a marked lowering of the plastic limits and a tendency towards a decrease in plasticity. There is no large shift in the plastic limits on the moisture scale with the Blanchester silt loam; however, this change is very significant considering the low percentage of organic matter in the original soil. The plasticity of this soil is dependent almost entirely upon the organic matter. If the lower plastic limit is con-

TABLE 3.—*The relation of organic matter to the plasticity of soils.*

	Moisture content					
	Upper plastic limit		Lower plastic limit		Plasticity number	
Soil	Original soil	Oxidized soil	Original soil	Oxidized soil	Original soil	Oxidized soil
	%	%	%	%		
Huntington fine sandy loam....	None	None	None	None	None	None
Chippewa silty clay loam.. ...	40.80	25.10	36.55	19.77	4.25	5.33
Toledo silty clay..	62.80	36.91	52.25	27.75	10.55	9.16
Blanchester silt loam..........	29.29	20.94	23.55	19.20	5.74	1.74

sidered as being near that moisture content at which a soil can be plowed, the practical significance of the incorporation of organic matter in surface soils can readily be seen.

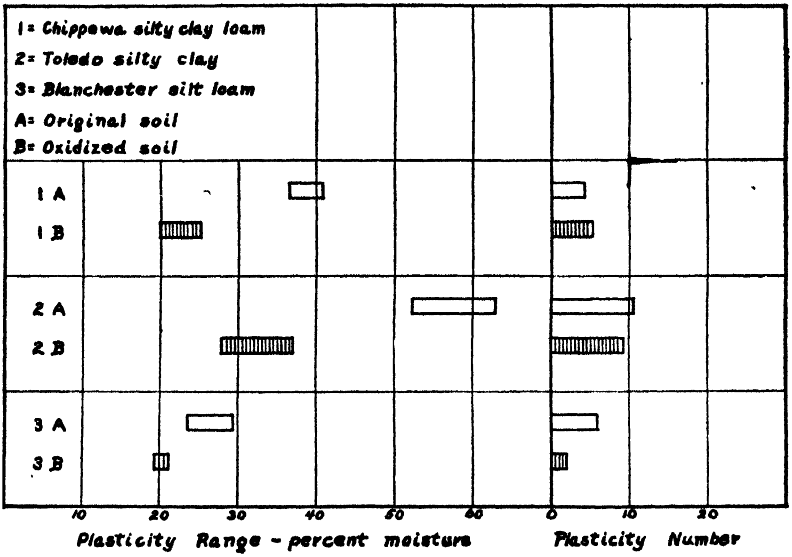

FIG. 1.—Plasticity of soils as affected by organic matter.

EFFECT OF OXIDATION OF ORGANIC MATTER UPON MECHANICAL ANALYSES OF SOILS

If the purpose of a mechanical analysis of a soil is to determine its ultimate particle size, that is, a separation of discrete mineral particles into sand, silt, and clay, then we should expect the final results to be influenced materially by the presence of organic matter. Particles of organic material would be incorporated with the different mineral particles. Organic material may serve as a cementing agent making complete dispersion of the soil aggregates very difficult. Complete dispersion could not be attained in the presence of the organic compounds with divalent cations. Robinson (4) states very definitely that organic matter prevents the accurate determination of the prime particle structure of a soil.

The results in Table 4 give the mechanical analyses of four different soils, determined before and after oxidation with H_2O_2. With the exception of the Blanchester silt loam, a soil containing very little organic matter, there has been an increase in the percentage of clay and a corresponding decrease in the percentage of sand and silt. The differences are large enough to change the soil type according to the U. S. Bureau of Soils classification. This increase in the clay content is due not only to the destruction of organic particles which would fall into the sand and silt fractions, but also to the more complete dispersion of the soil brought about by the oxidation process. The fractions from the oxidized soils were bright and free from any material adhering to their surfaces.

TABLE 4.—*The effect of oxidizing the organic matter in a soil upon its mechanical analysis.*

Soil	Origin*	Soil separates							
		Fine gravel %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Total sands %	Silt %	Clay %
Huntington	A	None	0.5	5.9	13.1	35.3	54.8	31.4	13.8
fine sandy loam	B	None	0.3	5.3	12.5	34.8	51.9	29.3	18.8
Chippewa	A	0.4	0.8	1.2	3.2	13.0	18.6	54.1	27.3
silty clay loam	B	0.5	0.6	0.9	2.2	13.0	17.2	49.5	33.7
Toledo	A	0.4	0.9	1.5	4.2	7.4	14.4	43.2	42.4
silty clay	B	0.2	0.3	0.6	1.5	6.2	8.8	40.7	50.5
Blanchester	A	0.5	0.7	1.2	3.6	9.6	15.6	59.7	24.7
silt loam	B	0.2	0.6	1.2	3.7	10.1	15.8	60.0	24.2

*A = Original soil; B = Oxidized soil.

There appears to be a splendid correlation in these four oxidized soils between the clay content and its absorptive capacity for cations. These correlations are shown in Table 5. These results suggest that the nature of the colloidal material from these soils, representing varying soil conditions in Ohio, is similar. Since these relationships have only been determined with a few soils, no definite conclusions can be drawn. Nevertheless, the results are significant because of the wide variation in the types of soil.

TABLE 5.—*The relation of absorptive capacity for cations to the clay content of the oxidized soils.*

Soil	Clay content %	Absorptive capacity mg. equiv.	Absorptive capacity x 100 / % clay
Huntington fine sandy loam.......	18.8	6.96	37.0
Chippewa silty clay loam..	33.7	13.17	39.0
Toledo silty clay................	50.5	18.65	36.9
Blanchester silt loam............	24.2	9.40	38.8

SUMMARY

A study of the relation of organic matter to certain physical properties of soils has given the following results:

1. Organic matter constitutes a large portion of the exchange complex of surface soils. The absorptive capacity for cations due to organic matter varied from 30 to 60%.

2. Oxidation of the organic matter produced a marked lowering of both the upper and lower plastic limits on the moisture scale. There was a slight tendency towards a decrease in the plasticity numbers.

3. Oxidation of organic matter caused an increase in the percentage of clay and a corresponding decrease in the percentage of sand and silt in the mechanical analyses of the soils studied.

4. A definite correlation existed between the clay content and absorptive capacity of the oxidized soils.

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THE RELATION OF ORGANIC FOOD RESERVES TO THE EFFECT OF CUTTING PASTURE WEEDS AT DIFFERENT STAGES OF GROWTH[1]

C. O. GRANDFIELD[2]

Considerable work has been done on the relation of time of cutting to maintenance of stands and organic food reserves in plants, particularly of alfalfa. Salmon, *et al.* (1)[3] found that the time of cutting materially affected the stand of alfalfa. Graber, *et al.* (2) conducted research work with alfalfa and other perennial herbaceous plants and found a definite relation between the supply of organic food reserves in the plants as they go into winter and the resulting stands. Smith (3) noted the effect of cutting bracken fern at different stages of development on its ability to survive. Aldous (4) has recently correlated the effect of cutting buck brush and sumac at different stages of growth and the amount of organic food reserves at the time of cutting. These results suggest that a study of the time of cutting may aid in solving the problem of controlling weeds in native grass pastures.

That the problem is worthy of investigation is shown by general observations in 92 counties in Kansas and by a survey made in August, 1928, in which 97 pastures chosen more or less at random over the entire state were examined in detail. Table 1 indicates the average densities and percentage of the different types of vegetation found in the 97 pastures arranged according to the different vegetative regions of the state. It will be seen that 93 of the pastures were below normal in density, and that of the vegetation present 26.4% consisted of weeds. Studies were therefore inaugurated to determine if there is a correlation between the time of cutting during the growing season, the organic food reserves stored in the roots, and injury to the stand. The study was pursued for one year only. Since it is not likely that the subject will be continued further in the immediate future, it seems desirable to present such results as were obtained for the use of other workers, although it is recognized that reliable conclusions cannot be obtained in a single year.

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[2] Assistant Professor of Agronomy in Cooperative Experiments. The writer wishes to express his appreciation for the helpful suggestions and criticisms given by Prof. A. E. Aldous and Dr. F. L. Duley of the Department of Agronomy and by Dr. E. C. Miller of the Department of Botany and Plant Pathology.

[3] Reference by number is to "Literature Cited," p. 713.

TABLE 1.—*Average density and percentage of different types of vegetation in the principal vegetative regions of Kansas.*

Vegetative region*	Number of pastures examined	Average density†	Number of pastures having a normal density	Number of pastures below a normal density	Percentage of vegetation Grasses	Weeds	Shrubs
Prairie grass..	35	6.89	4	31	60.3	33.6	6.1
Transitional..	23	6.33	0	23	68.5	31.4	1.0
Short grass...	39	5.97	0	39	73.1	23.8	3.0
State........	97	6.26	4	93	68.8	26.4	2.7

*As described by H. L. Schantz in Atlas of American Agriculture, Section E, Natural Vegetation.

†Ocular density.

EXPERIMENTAL

FIELD STUDIES

For this study three of the more common pasture weeds were selected, *viz.*, *Solidago rigida*, *Verbenia stricta*, and *Vernonia Baldwinii*. Fig. 1 shows the root systems of each of the three. *V. stricta* has a tap root with small secondary roots, *S. rigida* has a large number of roots branching off directly from the crown, and *V. Baldwinii* has an underground stem with a large number of secondary roots branching from it. Twelve plats, each 12 feet square, were located in a typical small farm pasture containing large numbers of *S. rigida* and *V. stricta* and a few *V. Baldwinii*. Every two weeks during the growing season of 1928 one of these plats was cut and counts made of the number of plants of each of the weeds first mentioned. The number of *V. Baldwinii* were so few as to make the results meaningless, hence no counts were recorded. A count of the number of plants surviving was made on May 20, 1929. Root samples for the determination of total carbohydrates and total N were taken on March 3 before growth started and at the time of cutting which occurred at intervals throughout the growing season.

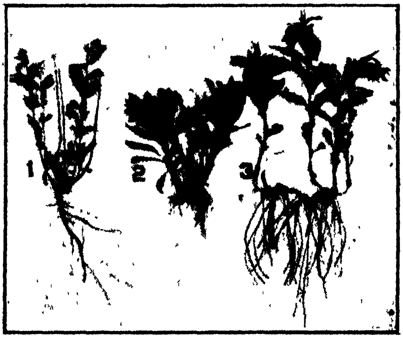

FIG. 1.—Rooting system of *Verbenia stricta* (1), *Solidago rigida* (2), and *Vernonia Baldwinii* (3).

The results of the counts made on *V. stricta*, as shown in Table 2, show that there was a reduction in the number of plants in all of the plats. The greatest reduction was secured from cutting on June 23, when the plants were in the bud stage of development. The same was true of *S. rigida*, except that the low point in the curve came with the cutting on July 21.

TABLE 2.—*Relation of date of cutting and survival.*

Plat No.	Date of cutting, 1928	Stage of growth when cut *V. stricta*	*S. rigida*	*V. Baldwinii*	Percentage of original stand on May 20, 1929 *V. stricta*	*S. rigida*
1	May 26	Vegetative	Vegetative	Vegetative	22.7	92.8
2	June 8	Bud	Vegetative	Vegetative	5.8	75.7
3	June 23	Bud	Vegetative	Vegetative	0.0	65.5
4	July 7	¼ bloom	Vegetative	Bud	13.3	61.3
5	July 21	½ bloom	Bud	Bud	5.8	58.3
6	Aug. 3	Full bloom	Bud	½ bloom	30.0	60.0
7	Aug. 19	Full bloom	½ bloom	¾ bloom	37.5	83.7
8	Sept. 1	Mature	Bloom	Full bloom	42.8	87.5
9	Sept. 15	Mature	Full bloom	Mature	21.4	100.0
10	Oct. 29	Mature	Mature	Mature	50.0	100.0

ORGANIC FOOD RESERVES

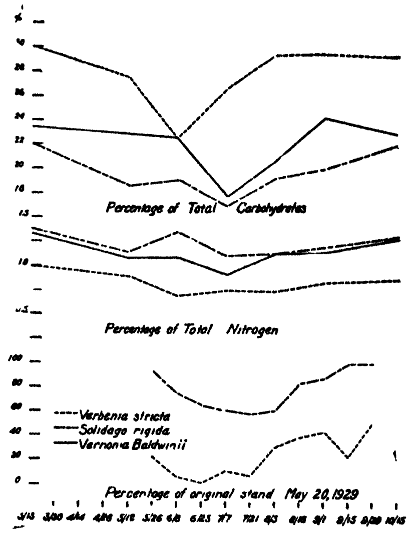

FIG. 2.

The material for analysis was prepared in the usual way. The analytical work for total carbohydrates and total N followed closely the official methods as outlined by the Association of Official Agricultural Chemists (5). A microscopic examination for starch of sections of the root samples after staining with iodine showed that none of the three plants stored reserve food in the form of starch.

The results of the laboratory analysis for total carbohydrates and total N on seven different dates of cutting of the three weeds are shown in Table 3 and the curves are plotted in Fig. 2. *V. stricta* contained the least amount of total carbohydrates on the plat cut June 8, i. e., two weeks earlier than the date of the most effective cutting which was June 23. For *S. rigida*, July 7 was the low point for total carbohydrates, which also was two weeks earlier than the date of the most effective cutting. However, the differences between the effectiveness of cutting on these dates were very small. In fact, considering the possibilities for error, it appears that such differences as were observed in the cuttings from June 8 to July 21 for *V. stricta* and from June 23 to August 3 for *S. rigida* should not be emphasized. The low point for the carbohydrates of *V. Baldwinii* was July 7.

For each of the weeds studied the low point for the total N was on the same date as the low point for total carbohydrates, and these low points occurred just before the bud stage of development of the plant.

TABLE 3.—*Total carbohydrates and total nitrogen in V. stricta, S. rigida, and V. Baldwinii expressed in percentage of dry weight.*

Date of sampling, 1928	*V. stricta*		*S. rigida*		*V. Baldwinii*	
	Carbohydrates*	Total N	Carbohydrates	Total N	Carbohydrates	Total N
	%	%	%	%	%	%
Mar. 23....	30.0	0.99	22.1	1.39	23.5	1.34
May 12....	27.6	0.89	18.5	1.14	22.7	1.07
June 8.....	22.5	0.69	19.2	1.35	22.6	1.08
July 7.....	26.4	0.75	16.6	1.11	17.6	0.91
Aug. 3.....	29.3	0.74	19.1	1.12	20.5	1.12
Sept. 1.....	29.4	0.83	19.9	1.19	24.1	1.13
Oct. 15....	29.2	0.96	21.7	1.31	22.6	1.29

*Total carbohydrates estimated as dextrose.

The data in Tables 2 and 3 are plotted in curves and shown in Fig. 2.

CONCLUSIONS

The results taken as a whole are in agreement with those of other workers in showing a definite period in the stage of development of the plant at which time the reserve organic food is at a low point. In each of the cases studied this low point occurs just before the plant began to show buds. It appears that during the rapid development of the stems and leaves of the plant, a large part of the carbohydrate and nitrogenous compounds being manufactured by the plant are used up, and until this rapid growth is completed there is not enough synthesized to allow for storage in the roots. This seems to occur when the plant is about ready to reproduce at which time there is a large leaf surface, and hence an opportunity for a rather rapid increase in the organic food reserves in the roots. Thus, in the case of *V. stricta* from the time the plant started budding to the time it was mature there was a 23.8% increase in the amount of total carbohydrates and a 16.8% increase in the total N. *S. rigida* and *V. Baldwinii* had about the same increases, as shown in Table 3. Under the conditions of this experiment, it is evident from these data that from the time of budding to the time the plant is in full bloom organic food reserves are being stored in the roots.

Theoretical considerations indicate that if the source of organic food supply can be cut off at the time when there is a low amount of reserve in the roots, there would be a tendency to starve the plant or at least stop the storage of the reserve which is necessary for the rapid growth and development of the plant the next season. The experimental data here presented appear to verify this deduction.

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ORGANIC MATTER EFFECTS ON SOIL[1]

T. J. DUNNEWALD[2]

It has been shown[3] that pine timber will invade either a soil which is high in lime or one leached of most of its basic substances and in an acid condition. When a soil is covered by timber, the organic matter derived from needles, leaves, rotten wood, etc., is deposited on the surface of the soil. Rain water dissolves the soluble part of this organic matter and the resulting weak solution penetrates the surface horizons of soil and starts a leaching process which finally removes the basic materials, leaving the soil acid.

The organic matter from the trees partakes of the nature of the soil on which the trees grow. That is, on the high-lime soil the pine needles contain more basic material and have a neutral or basic reaction, while on the acid soil the needles produced are also acid and low in basic material. This is shown in Table 1 where pine needles produced on basic and acid soils are compared.

The organic matter deposited on timbered areas also varies in the amount of soluble mineral and organic substances contributed to the soil solution, as shown in Table 2.

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[1] Contribution from Department of Agronomy, University of Wyoming, Laramie, Wyo. Received for publication February 25, 1930.

[2] Assistant in Soils Investigations.

[3] DUNNEWALD, T. J. Grass and timber distribution in the Big Horn Mountains. Jour. Amer. Soc. Agron., 22: 577–586. 1930.

TABLE 1.—*Pine needles from trees on acid and on basic soils.*

Soil No.	Source of organic matter	pH	Organic matter %	Ca, Mg oxides %	P, Fe, Al oxides %
Horizon 121A$_0$	Dead pine needles and wood on acid timbered soil, 0—⅜ inch	6.0	86.7	1.64	1.60
Horizon 1A$_0$	Pine needles and bark matted on basic timbered soil, 0–1 inch	6.4	72.4	3.23	1.89
Horizon TA$_0$	Pine needles, Telephone Canyon on high-lime, timbered soil	7.5	47.59	5.73	2.76

The organic matter which penetrates soil from grass vegetation differs in several respects from the organic matter derived from tree vegetation close by. Based upon the loss on ignition, Table 3 shows the percentage solubility of the organic matter from zones of a soil covered by grass and by timber, respectively.

TABLE 2.—*Solubility of various forms of organic matter.*

	10% NH_4OH-soluble humic substances		5% HCl-soluble substances		Water-soluble crenic	
Source of organic matter	Mineral %	Organic %	Mineral %	Organic %	Mineral %	Organic %
Pine needles on acid soil (121)	0.43	14.58	3.52	3.03	0.19	1.30
Pine needles on acid soil (6)	0.29	8.12	2.97	3.24	0.24	1.38
Pine needles on basic soil (1)	0.89	7.43	4.12	3.53	0.17	0.67
Pine needles on basic soil (Tel)	0.51	4.73	13.61	6.16	0.23	0.68
Leaf mold (basic)	0.45	2.26	20.58	12.58	0.72	1.35
Alfalfa leaves (basic)	2.76	4.54	2.10	3.28	1.40	0.77
Sphagnum moss (acid)	0.12	2.91	1.67	4.40	0.57	3.15
Aspen leaves on granite (acid)	0.09	4.22	2.35	2.61	0.26	0.84

TABLE 3.—*Solubility of the organic matter from zones of a soil covered by grass and by large pine trees.*

Soil No.	Total C per gram of dry soil (loss on ignition), grams	Soluble in hot water crenic %	Soluble in pine needles extract %	Soluble in 5% HCl %	Soluble in 10% NH_4OH humus %	Mineral matter in the humus from successive soil zones	
						Fe+Al +SiO_2 %	Ca+Mg %
			Black Acid Grass Soil				
Horizon 10 A$_0$	0.1801	2.10	7.4	8.4	41.6	14.5	None
Horizon 11 A$_1$	0.0990	2.70	12.8	10.6	57.5	9.6	2.40
Horizon 12 B	0.0700	3.40	14.3	13.9	35.6	7.8	3.04
Horizon 13 C	0.0580	3.04	16.2	25.3	28.3	21.6	12.40
			Grayish Acid Pine Soil				
Horizon 6 A$_0$	0.0727	1.13	11.5	13.7	37.3	11.2	Trace
Horizon 7 A$_1$	0.0367	1.28	17.1	17.2	36.5	27.4	Trace
Horizon 8 B	0.0219	1.00	33.3	14.6	20.2	66.6	Trace
Horizon 9 C	0.0150	1.31	18.0	22.2	20.1	22.1	24.6

The organic matter has accumulated to approximately three times the amount in the grass land as under the timber. About 1% of this organic matter from trees is soluble in water, while from 2 to 3% of that from grass is dissolved from the same zones.

The extract from pine needles increases the dissolved percentage most noticeably from the upper three zones of the timbered area. It is approximately as effective as 5% HCl in dissolving the organic matter of the soil zones.

The humus content is greatest by about one-third in the grass soil, indicating greater decomposition of the organic matter. Under grass, the mineral matter associated with the humus decreases in the lower zones but increases in the lower zones of the timbered area. Since more of the humus stays in solution in the grass areas, especially in the lower horizons of the soil, this condition may explain the observed fact[4] that dark grass soil becomes grayish and loses its organic matter from the bottom up when invaded by timber. That is, the lower zones lose their organic matter first and the surface zone becomes grayish last.

Table 3 also shows that the humus of the grass area retains more lime base, while that of the timbered soil has been completely leached of lime. The humus of the parent material (Nos. 13 and 9) appears to be rather similar in character beneath both the grass and timbered areas.

Whether the retention of lime by the humus of the lower horizons of prairie grass soil (as in the corn belt states) is connected with the unusual persistence of the organic matter in these acid soils, remains to be shown.

Since the organic matter produced partakes of the character of the soil on which it is grown, it follows, therefore, that when basic soil is invaded by timber the soil becomes leached by mild or basic organic matter, while an invaded acid soil is leached by humus of the so-called raw or acid kind.

TABLE 4.—*Material dissolved from various forms of organic matter by boiling distilled water.*

Kind of organic matter	pH	Total solids %	Organic matter %	Fe, Al, P_2O_5 %	Ca and Mg %
Spruce needles from acid soil (121) . .	5.8	1.49	1.30	0.07	0.08
Spruce needles from acid soil (6) . . .	6.0	1.64	1.38	0.08	0.07
Leaf mold from basic soil	7.0	2.07	1.35	0.05	0.32
Spruce needles from basic soil (1) . . .	6.4	0.84	0.67	0.06	0.10
Spruce needles from basic soil (Tel) .	7.5	0.91	0.68	0.07	0.15

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[4] MARBUT, C. F. Translation of Glinka's World Soil Groups and Their Development.

This humus, deposited on top of the soil beneath the trees, yields up soluble material to the rain water affecting the leaching power of the water upon the soil beneath, which it penetrates. From 1 to 2% of this surface organic matter dissolves in water,[5] as shown in Table 4.

It will be seen that pine needles from basic soil give up about half the amount of soluble material obtained from needles produced on acid soil, therefore, one would expect greater leaching power in the acid humus. The leaf mold also shows large leaching power indicating that perhaps organic matter from deciduous trees may accomplish podsolic effects in soil even sooner than needles from pines are able to do. Most of the soluble materials collected by the rain water are derived from the organic matter and a small additional amount comes from the soil. That is, more soluble material is found in the water when it passes through mixed soil and organic matter than when it passes through the organic matter alone. Also, different forms of organic matter vary in the amount of material made soluble in water, as shown in Table 5.

TABLE 5.—*Grams of material dissolved from organic matter and from a mixture of soil and organic matter by 200 cc of hot distilled water.*

Material	Total solids	Organic matter	Fe, Al, P oxides	Ca, Mg oxides
5 grams alfalfa leaves	0.1084	0.0384	0.0065	0.0038
5 grams alfalfa leaves + 5 grams acid soil No. 14	0.1079	0.0602	0.0078	0.0062
5 grams pine needles	0.0823	0.0692	0.0041	0.0037
5 grams pine needles + 5 grams acid soil No. 14	0.1021	0.0788	0.0065	0.0056
5 grams sphagnum moss	0.1861	0.1573	0.0072	0.0025
5 grams sphagnum moss + 5 grams acid soil No. 14	0.2658	0.2085	0.0080	0.0039
5 gram leaf mold	0.1035	0.0574	0.0023	0.0162
5 gram leaf mold + 5 grams basic subsoil	0.1163	0.0625	0.0110	0.0204

The acid sphagnum moss gave the most soluble material and pine needles least. In stimulating the solution of material from the soil itself, pine needles were second to the moss. Leaf mold stimulated the greatest solubility of sesqui-oxides from the soil. In a state of nature in timber land the rain water penetrates the surface organic matter, then enters the soil with its dissolved material. This solution reacts with the surface soil zone, gains some matter and perhaps loses some, and penetrates the second soil zone with a different concentration than when it entered the first zone. To simulate this process in the laboratory the following experiment was devised.

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[5] Russian analyses show that as much as 2 to 5% of the humus is soluble in water in the A_1 horizon and 5 to 10% in the A_2 horizon.

Ten grams of acid spruce needles were brought to a boil with 200 cc of distilled water, filtered, and the filtrate again brought to a boil with 10 grams of black acid prairie soil (No. 10). The soil was filtered off, one-fifth of the filtrate was taken for analysis, and the other four-fifths were brought to a boil with 8 grams of the second horizon (No. 11) of this soil. This process was continued with 6 grams of the third horizon (B) and 4 grams of the parent material (C) horizon. A portion of each filtrate, representing 2 grams of soil, was analyzed as shown in Table 6.

TABLE 6.—*Grams of material dissolved in filtrates from 2 grams of successive horizons of a black, acid, grass soil.*

Material	Total solids	Organic matter	Oxides of Fe, Al, P	Oxides of Ca, Mg
Filtrate from pine needles	0.0328	0.0270	0.0016	0.0015
Filtrate from zone A_0, soil 10......	0.0312	0.0255	0.0040	0.0025
Filtrate from zone A_1, soil 11......	0.0354	0.0253	0.0045	0.0028
Filtrate from zone B, soil 12......	0.0319	0.0201	0.0053	0.0027
Filtrate from zone C, soil 13......	0.0343	0.0189	0.0085	0.0036

The rain water as it makes its way downward in the grass covered soil loses its dissolved organic matter and takes on more and more mineral matter. The humus, also, is more highly mineralized with depth, as shown in Table 3.

From one-half to two-thirds as much matter is dissolved from the leached timbered soil as from the black prairie grass soil (Table 7). The previous leaching of the timbered soil horizons makes them less soluble than the prairie grass soil. The small amount of bases dissolved from the acid soils is very similar in both the timbered and grass areas.

TABLE 7.—*Grams of materials dissolved in filtrates from 2 grams of successive horizons of a gray, acid timbered soil.*

Material	Total solids	Organic matter	Oxides of Fe, Al, P	Oxides of Ca, Mg
Filtrate from pine needles	0.0328	0.0270	0.0016	0.0015
Filtrate from zone A_0, soil 6......	0.0218	0.0168	0.0018	0.0031
Filtrate from zone A_1, soil 7.......	0.0284	0.0125	0.0031	0.0033
Filtrate from zone B, soil 8......	0.0261	0.0146	0.0021	0.0026
Filtrate from zone C, soil 9......	0.0221	0.0154	0.0025	0.0044

Two other soil profiles taken in close proximity, one in the open grass area and the other in heavy timber, were treated after the same manner as above. The results are shown in Table 8.

This set of samples again shows that from one-half to two-thirds as much soluble material is obtained from the zones of timbered soil as from zones of grass soil, with the exception of Fe, Al, and P where more soluble iron is found in the lower zones of the timber soil.

TABLE 8.—*Grams of materials dissolved by pine needle extract from 2 grams of successive horizons of acid-grass and acid-timber soil.**

Material	Total solids	Organic matter	Oxides of Fe, Al, P	Oxides of Ca, Mg
Dark Acid Grass Soil				
Filtrate from 2 grams pine needles.	0.0328	0.0270	0.0016	0.0015
Filtrate from 2 grams soil 117 zone A_0	0.0414	0.0352	0.0014	0.0044
Filtrate from 2 grams soil 118 zone A_1	0.0545	0.0396	0.0025	0.0037
Filtrate from 2 grams soil 119 zone B	0.0268	0.0234	0.0017	0.0039
Filtrate from 2 grams soil 120 zone C	0.0306	0.0262	0.0009	0.0025
Gray-brown Acid Timber Soils				
Filtrate from 2 grams soil 122 zone A_0	0.0269	0.0222	0.0024	0.0025
Filtrate from 2 grams soil 123 zone A_1	0.0286	0.0181	0.0035	0.0028
Filtrate from 2 grams soil 124 zone B	0.0234	0.0151	0.0070	0.0018
Filtrate from 2 grams soil 125 zone C	0.0302	0.0221	0.0055	0.0019

*Samples taken a short distance apart.

Since these samples were taken so close together as to eliminate differences in rainfall, annual temperature, or drainage, it seems necessary to conclude that podsolization of soil here and elsewhere must be due entirely to the leaching effects of organic matter deposited on the surface of the soil. Whether variations in podsol soils are related to variations in character of the organic matter deposited on top of the soil by tree vegetation, remains to be demonstrated.

SUMMARY

Organic matter partakes of the nature of the soil on which it is produced. The partial solution of this organic matter in water exerts varying effects on soil in dissolving and transporting materials dissolved from it. Sweet humus from basic soil is less soluble than acid humus from acid soil.

Organic matter accumulates about three times as much under grass as under timber and is from two to three times as soluble in water where it accumulates in acid soil. There is more humus in the grass organic matter and its mineral content decreases with depth in the soil.

Increased solubility of the organic matter with increased depth probably explains the podsolization of dark grass soil from the bottom toward the surface rather than from the surface downward.

Persistence of lime in the humus of the acid prairie soil may explain the persistence of this organic matter under acid conditions as seen in the corn belt area of central United States.

THE CHEMICAL COMPOSITION OF CONSECUTIVE CUTTINGS OF *Andropogon virginicus* AND *Danthonia spicata*[1]

R. B. DUSTMAN AND A. H. VAN LANDINGHAM[2]

In an earlier issue of this JOURNAL (1)[3] an account was given of a study of the chemical composition of *Andropogon virginicus* and *Danthonia spicata* at successive growth stages as found in typical upland locations in West Virginia. The results showed that the early growth of both grasses is characterized by a relatively high protein and low fiber content as compared with the later growth. As the season advances, there is a steady decline in protein content and corresponding rise in fiber as the plants approach maturity. These progressive changes are distributed across the months of summer and early fall.

One of the objects of this earlier study was to ascertain the approximate time and stage of growth at which the nutritive value of these grasses begins to fall off in marked degree. This period was found to be roughly the month intervening between early June and early July in the years studied. By the end of the first week of July, the leaves of both grasses were somewhat toughened and the fiber content had increased to a fairly high level while the protein was reduced to approximately two-thirds of its value of one month earlier. It was thus apparent that from the standpoint of composition and, therefore, of grazing value, the spring and early summer growth affords a pasturage much superior to that supplied by these grasses later in the season.

It then became desirable to find out, if possible, whether or not a system of cutting at regular intervals would keep the grasses in an actively growing condition and thus maintain their more desirable feeding qualities at or near the level obtaining during early summer. To secure information on this point the interval between consecutive cuttings was chosen at one month for each of the two grasses, and samples were taken accordingly. At the same time and from adjacent areas samples were collected from plants not previously cut during the current season, thus allowing for a comparison of the composition of the monthly cuttings with similar plants allowed to develop normally and continuously.

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[1] Contribution from the Department of Agricultural Chemistry, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the director as Scientific Paper No. 86. Received for publication February 28, 1930.

[2] Head of Department and Graduate Assistant, respectively.

[3] Reference by number is to "Literature Cited," p. 724.

LOCATION AND SAMPLING OF PLATS AND METHODS OF ANALYSIS

The samples of *A. virginicus* and *D. spicata* herein reported were taken from the same locations as those previously reported (1) for the year 1928. Thus the present samples of *A. virginicus* were collected from the same area of "open hillside uncut meadow" as the 1928 samples, while the present samples of *D. spicata* were likewise collected from the same "open sandy ridge" as the 1928 samples. The results for the two different years are therefore comparable for corresponding dates and growth stages.

On June 10, 1929, at the time the first samples for the present studies were collected, areas of uniform growth of each of the two grasses were staked off and cut with a sickle as close to the ground as was conveniently possible. These areas were maintained for the subsequent consecutive cuttings. Additional adjacent areas of previously uncut plants were harvested in the same manner, whenever consecutive cuttings were made. On August 10, in order to secure a suitable sample of *A. virginicus*, it was found desirable to supplement the third cutting with some 2nd-cutting material grown during the same 31-day period, July 10 to August 10. This 2nd-cutting material was taken from the adjacent area cut for the first time on July 10 and again cut for this purpose on August 10. This was done in such a manner that the final sample was represented by one-half 3rd-cutting and one-half 2nd-cutting material. On September 11, a similar plan was followed, the final sample consisting of one-half 4th-cutting and one-half 3rd-cutting material, the latter taken from the adjacent area previously cut on July 10, and again on August 10.

After being collected, the samples were taken to the laboratory, brought to air dryness with the aid of an electric fan, ground, and stored in half-gallon glass jars for analysis. The analytical methods were the customary ones of the Association of Official Agricultural Chemists employed in feed control work.

DISCUSSION

Table 1 shows the composition of the monthly cuttings of *A. virginicus* and Table 2 gives the corresponding data for *D. spicata*. In the former it is seen that the protein content of the plants permitted to grow in a normal uninterrupted manner fell from 11.16% on June 10 to 5.88% on September 11, the period of most rapid decline being the month between June 10 to July 10. This is more clearly shown by the graph in Fig. 1 (primary cuttings) and is in accord with the results secured in the two preceding years. Since the fiber content remains approximately constant until mid-August, the decline in protein is perhaps best accounted for by the elaboration and storage of carbohydrate materials. The effect of consecutive cutting at monthly intervals on *A. virginicus* is seen to lessen materially the decline in protein content throughout the summer, although in the case of this grass reduction was not entirely prevented. The results on this point were more gratifying with *D. spicata*, as will be pointed out later. Fig. 1 shows the trend of protein content for both primary and consecutive cuttings of *A. virginicus* and also the differences resulting from the two methods of handling.

TABLE 1.—*Composition of monthly cuttings of A. virginicus on moisture-free basis, 1929.*

Date harvested	Description	Crude protein %	Crude fiber %	N-free extract %	Ether extract %	Ash %
June 10	New growth up to 15 inches	11.16	32.9	48.7	2.34	4.92
July 10	2nd cutting, leaves 6 to 16 inches	9.67	33.2	50.7	2.09	4.29
	Previously uncut, leaves 6 to 20 inches	7.76	32.6	54.7	1.49	3.44
Aug. 10	Mixed 2nd and 3rd cuttings, leaves 4 to 15 inches	8.97	33.8	51.4	2.33	3.45
	Previously uncut, leaves 8 to 20 inches	7.24	32.9	54.1	2.13	3.58
Sept. 11	Mixed 3rd and 4th cuttings, leaves 4 to 10 inches	8.59	34.9	51.0	1.82	3.70
	Previously uncut, leaves 10 to 20 inches	5.88	36.8	51.6	1.84	3.88

TABLE 2.—*Composition of monthly cuttings of D. spicata on moisture-free basis, 1929.*

Date harvested	Description	Crude protein %	Crude fiber %	N-free extract %	Ether extract %	Ash %
June 10	New growth up to 18 inches, in head but before bloom	8.47	36.5	48.9	2.06	4.07
July 10	2nd cutting, leaves 2 to 6 inches	9.04	33.1	50.1	3.14	4.60
	Previously uncut, seeds partly matured	5.38	37.8	50.3	2.52	3.98
Aug. 10	3rd cutting, leaves 2 to 6 inches	8.53	35.4	46.8	4.32	4.91
	Previously uncut, seeds matured, culms dead	4.94	36.3	51.8	3.10	3.82
Sept. 11	4th cutting, leaves 1 to 4 inches	8.44	32.8	48.5	5.36	4.91
	Previously uncut, some new growth	5.32	35.8	51.6	3.90	3.38

Turning now to a consideration of *D. spicata*, Table 2 and Fig. 2 show the corresponding data for this grass. Here, also, the most rapid fall in protein content of grass allowed to grow uninterruptedly occurred during early summer. Toward the end of the season there was a slight upward swing due apparently to the beginning of new growth brought on by late summer and early fall rains. This decline paralleled that observed for the same grass in 1928. The season of 1929 was earlier than that of 1928 as shown by the records of growth of both grasses, and hence they had reached a more advanced stage in 1929 than on the corresponding date in 1928. Thus, the growth stage of *D. spicata* on June 10, 1929, is recorded as "in head but before bloom" and the protein content as 8.47%, whereas the growth stage on June 7, 1928, is given as "not yet in head" and the protein content as 11.49%. Fig. 2 brings out the general direction of change of protein content of *D. spicata*, both when growing uninterruptedly and when subjected to regular clipping at monthly intervals. The differences in protein content between the regularly cut and the previously uncut samples are quite pronounced. It may be seen that regular clipping at monthly intervals has maintained this important type of food substance at a relatively high level throughout the season. In fact, the nutritive value of the grass as it was found on June 10 has been held practically unchanged across a period of three months and well into September. During this period the fiber not only was kept from increasing but was actually reduced, while the minerals suffered but slight change.

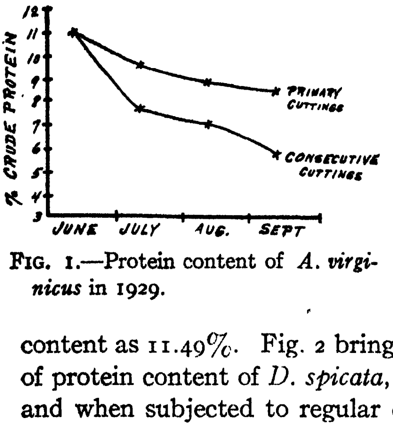

FIG. 1.—Protein content of *A. virginicus* in 1929.

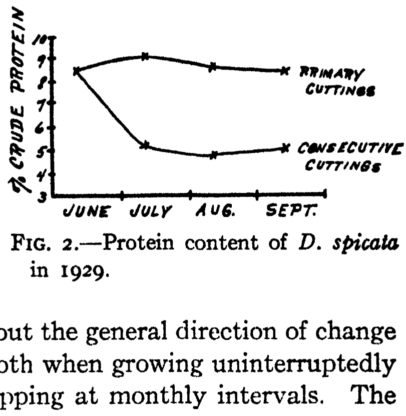

FIG. 2.—Protein content of *D. spicata* in 1929.

As was stated earlier in this report, an interval of one month between consecutive cuttings was arbitrarily chosen for a working basis. That this succeeded admirably for *D. spicata* is evident from Table 2 and Fig. 2, but that it did not work so well for *A. virginicus* is likewise apparent from a consideration of Table 1 and Fig. 1. Once well started, *A. virginicus* grows rather rapidly and becomes tough and hardened in a relatively short length of time. Apparently the clippings were not of sufficient frequency to hold this grass in a tender, succulent condition. This is shown by the slight but consistent rise in fiber and corresponding fall in protein throughout the summer months. A comparison of the length of leaves of the two grasses on the dates the consecutive cuttings were made also indicates clearly the more rapid rate of growth of *A. virginicus*. Perhaps if the cuttings of this grass had been carried out on a bi-weekly basis its original high protein and low fiber character would have been more nearly maintained. Whatever may have been the effect of more frequent cuttings the interesting fact remains that monthly cuttings both delayed and reduced the usual midsummer decline in nutritive value for this grass and maintained the desirable character of *D. spicata* as it normally occurs in early June. So far as the authors are aware there are no digestibility data available for *A. virginicus*. Jordan (2) harvested *D. spicata* at the full bloom stage and ran some digestion experiments with sheep. The outcome showed *D. spicata* to differ but little in digestibility from other upland grasses, including timothy and redtop, when harvested at the same stage.

POSSIBLE APPLICATION

In the previous article (1) relating to these grasses their prevalence in the meadow and grazing lands of large areas in the eastern United States was mentioned, and the possibility of their utilization by suitable methods of grazing was suggested. It has long been known that the early growth of pasture grasses is highly nutritious. But that it might be possible to retain this high nutritive character of pasture herbage throughout the summer season by proper systems of grazing has not been so generally recognized.

In an extensive series of investigations at Cambridge, Woodman and his coworkers (3) have shown that under the climatic and soil conditions obtaining in England, a system of cutting pasture grasses at 3-week intervals is highly satisfactory from the general standpoint of composition, digestibility, nutritive value, and yield. They state that under this system pasture grass never reaches the stage of growth at which lignification sets in, but that at the end of a 3-weeks' period of growth it still retains the highly digestible character which it possessed at the end of a week's or fortnight's growth. The results of their findings relative to a system of cutting at monthly intervals will be awaited with interest.

If pasture grasses can be maintained in an early growing and highly nutritious condition by systems of cutting at 3-, 4-, or 6-week intervals without deteriorating influence on the grasses themselves, it is reasonable to suppose that entirely analogous results could be obtained by grazing pasture lands in corresponding systems of rotation with uninterrupted periods of growth between. This is of great significance to those stockmen and farmers who depend upon pasturage for a considerable production of feed for their livestock. It is interesting, also, to know that even such wild and coarse-growing grasses as *A. virginicus* can be brought into utilization and made to furnish their portion of pasturage in suitable condition. That somewhat different grazing intervals may be desirable for different types of grasses is indicated by a comparison of the composition of the monthly cuttings of *A. virginicus* and *D. spicata* with that of the uninterrupted growths. Nevertheless, an interval could be chosen to suit the predominating species, or so chosen as just to prevent lignification in those grasses present which tend toward coarsening or toughening in greatest degree. Mature and old growth of grasses, especially that of the tougher varieties, should be avoided or removed.

SUMMARY

A continuation of the study on the chemical composition of *A. virginicus* and *D. spicata* at various growth stages has yielded the following results for the season of 1929:

1. Under a system of cutting at regular monthly intervals the protein, fiber, and mineral content of *D. spicata* as it normally occurred in early June was maintained throughout the summer and early fall without the usual deterioration in nutritive quality.
2. In the case of *A. virginicus* cutting at monthly intervals did not entirely prevent a decline in protein and corresponding rise in fiber content, but it materially reduced the tendency toward such changes.
3. The bearing of these results on the utilization of wild pasture grasses and on systems of rotational grazing has been suggested.

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COMPUTATION OF FERTILIZER MIXTURES FROM EXTRA-HIGH ANALYSIS FERTILIZERS[1]

E. P. DEATRICK[2]

A number of writers have illustrated methods for computing fertilizer mixtures from materials of various sources. The fertilizer carriers used in these computations have been almost exclusively single- and double-component ones. So far as the writer knows, no mention has been made of the possibility of using the new triple-component extra high analysis fertilizers which are now appearing[3] on the market.

Agronomists are beginning to recommend fertilizer ratios indicated by points of intersection of the decimal rulings on "the fertilizer triangle" (1, 2, 3).[4] (Graph I.) The 24 ratios recommended by the New England and the Central State Conferences were selected in this way. It is of timely interest, therefore, to note that the ratios of but 5 of the 11 extra high analysis fertilizers on the market coincide with those indicated by the points of intersection of these decimal rulings on the triangle. Concerning this point, Baer (1) writes, "if they [these fertilizers] are to be offered directly to the consumer as they stand, then consideration may well be given to making them conform to the triangle scheme." This will be especially advisable, as those recommending fertilizer ratios come more and more to limit themselves to ratios indicated by the points of intersection in the decimal scheme, and as farmers come to realize more and more the saving in freight, hauling, and spreading when the high analysis mixtures are used.

Doubtless, applications of these extra high analysis fertilizers will be restricted largely to truck crops until machines come into general use which are capable of spreading quantities small enough for field crops. Nevertheless, there may actually develop two new forms of home mixing—one of using these fertilizers as a base to mix with non-fertilizing materials, such as soil or limestone, to secure the greater bulk needed for spreading on general crop land; and another

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[1] Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved by the Director for publication as Scientific Paper No. 84. Received for publication March 8, 1930.

[2] Associate Agronomist.

[3] Samples of 11 of these fertilizers have been received thus far, *viz.*, 15–30–15, 16.5–16.5–20, 15.5–15.5–19, 15–11–26.5 (Synthetic Nitrogen Corporation); 12–24–12, 10–20–15, 10–30–10 (American Cyanamid Company); 9–27–9, 9–18–18 (Armour and Company); and 4–16–10, 8–16–14 (York Chemical Works). These figures refer to percentages of N (or NH_3), P_2O_5, and K_2O, respectively.

[4] Reference by number is to "Literature Cited," p. 738.

of using them with various carriers to make a mixture of a desired analysis or its equivalent. Commercial mixers are already finding it advantageous to use some of these fertilizers as base materials.

It might be helpful, therefore, to have formulae for determining the kinds and the amounts of the ingredients needed to change these high analysis fertilizers into mixtures of the analyses more commonly demanded, or into mixtures that are the equivalent of these, provided, of course, that by the use of such formulae the solutions are simplified.

DETERMINATION OF KIND OF CARRIERS NEEDED IN CHANGING THE RATIO

In changing a "basic" material into either a mixture or the equivalent of a mixture of another analysis, the first step is the determination of the kind of carriers needed in changing the ratio. The kind of carriers that must be added to a "base" fertilizer to change it into one that is the equivalent of a fertilizer of another ratio can generally be determined easily by inspection, if the ratios of the base and of the desired fertilizer be simplified.

INSPECTION METHOD

Problem I.—(a) What, if anything, must be added to a 10-30-10 to make the equivalent of a 4-12-4, and (b) to a 15-30-15 to make the equivalent of a 2-14-4?

Simplify the ratios so that the nitrogen figures are unity, and subtract each figure in the high analysis simple ratio from the corresponding figure in the simple ratio of the desired analysis, as follows:

Analyses[5]		*Simplified ratios*	
(a) 4-12-4	(b) 2-14-4	1 3 1	1 7 2
10-30-10	15-30-15	1 3 1	1 2 1
		0 0 0	0 5 1

In Problem Ia the two analyses are of the same ratio, and it is therefore obvious that nothing need be added. In case b it is evident that both phosphoric acid (P_2O_5) and potash (K_2O) must be added. In certain other cases, however, the determination is not so simple. In Problem II, which follows, there is a difference in both the phosphoric acid (P_2O_5) and the potash (K_2O) ratio figures, but the difference is not positive in both cases.

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[5] The lines between the figures in the analyses are hyphens, not negative signs, and are therefore omitted in the simplified ratios where negative signs are sometimes needed to indicate negative quantities.

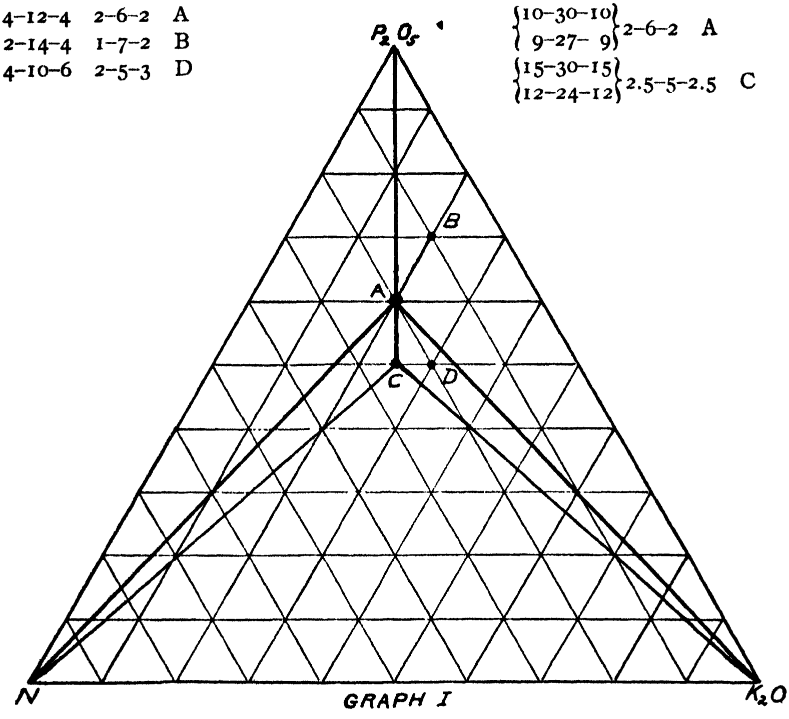
Problem II.—What, if anything, must be added to a 9–27–9 fertilizer to make of it the equivalent of a 4–10–6 fertilizer?

Analyses	*Simplified ratios*
4–10–6	1 2.5 1.5
9–27–9	1 3.0 1.0
	—0.5 0.5

In cases of this kind a method for eliminating all trial and error would be of help.

4–12–4	2–6–2	A
2–14–4	1–7–2	B
4–10–6	2–5–3	D

10–30–10 9–27– 9	2–6–2	A
15–30–15 12–24–12	2.5–5–2.5	C



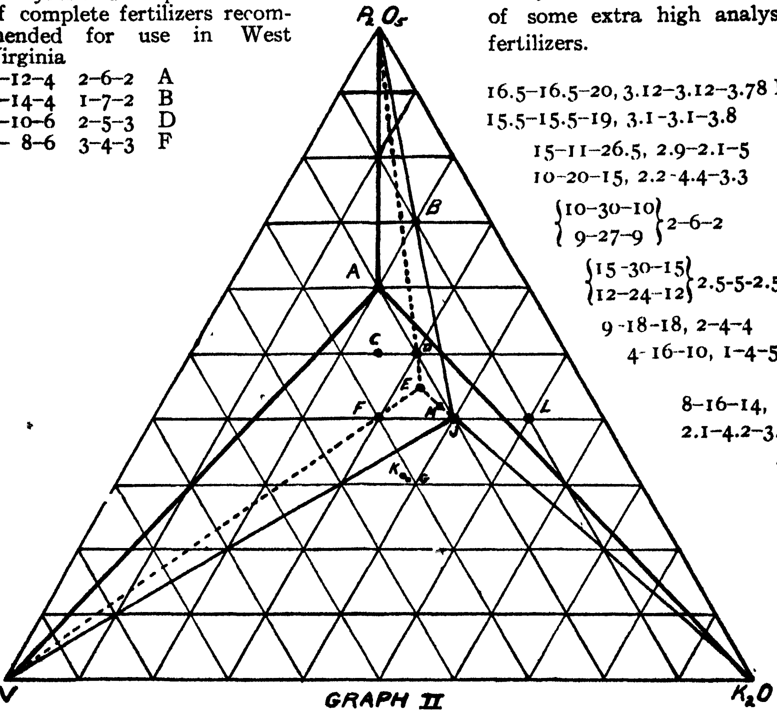
GRAPH METHOD

All trial and error may be eliminated and the additive carriers may be determined at a glance if points indicating the two ratios are plotted on triangular coordinate paper as in Graph I. Here the vertices of the triangle represent 100% of the amount of N, P_2O_5, and K_2O in the fertilizer and the base line opposite each angle represents 0%. A point on the boundary lines represents, then, a two-component material, and a point within the triangle represents a three-component material whose components are the materials plotted at the vertices, as explained in detail by Baer (1).

Now in Problem Ia the ratios of the two fertilizers 4–12–4 and 10–30–10 are the same, i.e., 1–3–1 (or 2–6–2 on the decimal basis), and hence both are represented by the same point A (Graph I). In case b the 1–7–2 ratio of the 2–14–4 fertilizer is plotted at point B, and the 1–2–1 (or 2.5–5–2.5) of the 15–30–15 is plotted at point C (Graph I). The position of B in the triangle C, P_2O_5 and K_2O indicates that the equivalent of a 2–14–4 can be made by adding phosphoric acid (P_2O_5) and potash (K_2O) to a 15–30–15—the materials indicated at the vertices of this inner triangle.

Analyses and simplified ratios of complete fertilizers recommended for use in West Virginia

4–12–4	2–6–2	A
2–14–4	1–7–2	B
4–10–6	2–5–3	D
6– 8–6	3–4–3	F



GRAPH II

Analyses and simplified ratios of some extra high analysis fertilizers.

16.5–16.5–20,	3.12–3.12–3.78	K
15.5–15.5–19,	3.1–3.1–3.8	G
15–11–26.5,	2.9–2.1–5	H
10–20–15,	2.2–4.4–3.3	E
10–30–10 9–27–9	2–6–2	A
15–30–15 12–24–12	2.5–5–2.5	C
9–18–18,	2–4–4	J
4–16–10,	1–4–5	L
8–16–14,	2.1–4.2–3.7	M

In Problem II the ratio 1–2.5–1.5 (or 2–5–3) of the 4–10–6 is represented by the point D (Graph I), and that of 1–3–1 (or 2–6–2) of the 9–27–9 is represented by the point A (Graph I). The position of D in the triangle A, K_2O and N, indicates that the equivalent of a 4–10–6 can be made by adding nitrogen and potash to a 9–27–9 fertilizer. Its position in the triangle A, K_2O, C indicates also that it can be made by adding potash to a mixture of a 9–27–9 and a 15–30–15.

The plotting of a series of ratios of the extra high analysis fertilizers and of those of desired fertilizers, as was done in Graph II, makes possible the illustration of a number of points. Not only does the position within a triangle indicate which two carriers must be added, but a position on a line indicates, in such a case, the one carrier that needs to be added. For instance, in Graph II, 2–14–4 or 1–7–2 (B) can be made from a 9–18–18 or 2–4–4 (J) by adding only phosphoric acid (P_2O_5). Furthermore, positions will show just which extra high analysis fertilizers need be changed the least to make the equivalent of a fertilizer of a desired analysis. For example, while the equivalent of a 4–10–6 or 2–5–3 (D) can be made by adding nitrogen and potash to a 9–27–9 or 2–6–2 (A), it can be made more easily by adding only phosphoric acid to a 10–20–15 or 2.22–4.44–3.33 (E), as indicated by its position on the line E, P_2O_5. A table for the rapid conversion of fertilizer analyses into ratios that may be plotted on the decimal triangle is given on page 730.

USE OF AN ALGORITHM IN FERTILIZER PROBLEMS[6]

The kind of carriers that must be added in such cases as those just cited may also be determined by the following algorithm:

	1	2	3	4	5	6
(a)	K_1	P_1	N_1	N	P	K
(b)	$-K$	$-P$	$-N$	N_1	P_1	K_1
(c)				0	$-(NP_1-N_1P)$	$-(NK_1-N_1K)$
(d)				$+(NP_1-N_1P)$	0	$-(PK_1-P_1K)$
(e)				$+(NK_1-N_1K)$	$+(PK_1-P_1K)$	0

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[6] This is an algorithm useful in problems involving eliminations. The numbers in line (c) of the algorithm, 0, $-(NP_1-N_1P)$, $-(NK_1-N_1K)$, are obtained by multiplying each of the numbers N, P, and K, [line (a) columns 4, 5, and 6.] by N_1 [line (a) column 3]; each of the numbers N_1, P_1, and K_1, [line (b) columns 4, 5, and 6] by $-N$ [line (b) column 3]; and adding the products of the multiplications of the same columns. The numbers in lines (d) and (e) are similarly obtained by multiplying the numbers mentioned as multiplicants [i.e. numbers in lines (a) and (b) columns 4, 5, and 6] first by P_1 and $-P$; and then by K_1 and $-K$; and adding the respective results. When X is positive, there are four possible combinations of signs for Y and Z. Likewise, this is the case when X is negative. The cases where we have a positive X and a negative Y combined with a positive Z, or a negative X and a positive Y combined with a negative Z, can be shown by a series of inequalities not to arise in these problems. When X, Y, or Z are found to be equal to zero, the matching of

Table for computing percentages based on the total weight of fertilizer to percentages based on the weight of the plant nutrients themselves.

Sum of percentage of $N-P_2O_5-K_2O$ (N, P_2O_5 and K_2O percentages are based on weight of fertilizer)	Percentages based on weight of plant nutrients themselves equivalent to percentages (from 1 to 16) based on the total weight of fertilizer															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
12	8.333	16.666	24.999	33.332	41.665	49.998	58.331	66.664	74.997	83.330	91.663	100.000				
13	7.692	15.384	23.076	30.768	38.460	46.152	53.844	61.536	69.228	76.920	84.612	92.304	100.000			
14	7.143	14.286	21.429	28.572	35.715	42.858	50.001	57.144	64.287	71.430	78.573	85.716	92.859	100.000		
15	6.667	13.334	20.001	26.668	33.335	40.002	46.669	53.336	60.003	66.670	73.337	80.004	86.671	93.338	100.000	
16	6.250	12.500	18.750	25.000	31.250	37.500	43.750	50.000	56.250	62.500	68.750	75.000	81.250	87.500	93.750	100.000
17	5.882	11.764	17.646	23.528	29.410	35.292	41.174	47.056	52.938	58.820	64.702	70.584	76.466	82.348	88.230	94.112
18	5.556	11.112	16.668	22.224	27.780	33.336	38.892	44.448	50.004	55.560	61.116	66.672	72.228	77.784	83.340	88.896
19	5.263	10.526	15.789	21.052	26.315	31.578	36.841	42.104	47.367	52.630	57.893	63.156	68.419	73.682	78.945	84.208
20	5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000	55.000	60.000	65.000	70.000	75.000	80.000
21	4.762	9.524	14.286	19.048	23.810	28.572	33.334	38.096	42.858	47.620	52.382	57.144	61.906	66.668	71.430	76.192
22	4.545	9.090	13.635	18.180	22.725	27.270	31.815	36.360	40.905	45.450	49.995	54.540	59.085	63.630	68.175	72.720
23	4.348	8.696	13.044	17.392	21.740	26.088	30.436	34.784	39.132	43.480	47.828	52.176	56.524	60.872	65.220	69.568
24	4.167	8.334	12.501	16.668	20.835	25.002	29.169	33.336	37.503	41.670	45.837	50.004	54.171	58.338	62.505	66.672
25	4.000	8.000	12.000	16.000	20.000	24.000	28.000	32.000	36.000	40.000	44.000	48.000	52.000	56.000	60.000	64.000
26	3.846	7.692	11.538	15.384	19.230	23.076	26.992	30.768	34.614	38.460	42.306	46.152	49.998	53.844	57.690	61.536
27	3.704	7.408	11.112	14.816	18.520	22.224	25.928	29.632	33.336	37.040	40.744	44.448	48.152	51.856	55.560	59.264
28	3.571	7.142	10.713	14.284	17.855	21.426	24.997	28.568	32.139	35.710	39.281	42.852	46.423	49.994	53.565	57.136

Remarks: In plotting fertilizer analyses on the "decimal triangle", the fertilizer analyses must be reduced to decimal ratios, i.e. the percentages based on the total weight of the fertilizer must be changed to percentages based on the weight of the nutrients in the fertilizer. For such changes the above table will be found of value.

For example, a 4–10–6 fertilizer contains 20% of plant nutrients based on the weight of the fertilizer: Then

	Percentage based on weight of fertilizer	is	Percentage based on weight of nutrients in fertilizer	As secured from table See intersection of Line	and Column
	4	"	20	20	4
	10	"	50	20	10
	6	"	30	20	6
And in case of 10–20–15*					
	4	"	22	18	4
	8	"	44	18	8
	6	"	33	18	6

The decimal ratios then are 2–5–3 for the 4–10–6, and 2.2–4.4–3.3 for the 10–20–15.

*Since the table does not give figures for analyses totaling as much as 45%, the 10–20–15 analysis must be reduced, as for instance to a 4–8–6, with a total of 18% which comes within the range of the table.

Where N P K equals the N, P_2O_5, and K_2O figures of the simplified ratio of the fertilizer of the desired analysis and $N_1P_1K_1$ equals the N, P_2O_5, and K_2O figures of the simplified ratio of the extra high analysis fertilizer, the determining expressions are:

$NP_1 - N_1P$; $NK_1 - N_1K$; and $PK_1 - P_1K$ (read NP_1 minus N_1P, etc.), which for simplicity are designated as X, Y, and Z.

Then if X is —
and Y is — Make nitrogen equivalent
but if Y is + or 0 Make potash equivalent
But if X is +
and Z is — Make phosphoric acid equivalent
but if Z is + or 0 Make potash equivalent

Thus, in Problem I b:

2–14–4	1, 7, 2	$X(\text{i.e.})NP_1 - N_1P = 2 - 7 = -5$	Therefore, make the nitrogen equivalent.
15–30–15	1, 2, 1	$Y(\text{i.e.})NK_1 - N_1K = 1 - 2 = -1$	

The tonnages containing the equivalent of nitrogen are the following: Since

7.5 tons of 2–14–4 contain 15–105 – 30 units of N, P_2O_5, and K_2O and
1 ton of 15-30-15 contains 15– 30 - 15 units of N, P_2O_5, and K_2O,
the difference is 75 and 15 units of P_2O_5, and K_2O, and these amounts therefore must be added to 1 ton of 15–30–15 to make the equivalent of 7.5 tons of 2–14–4.

In the case of Problem II

4–10–6	1, 2.5, 1.5	$X(\text{i.e.})NP_1 - N_1P = 3 - 2.5 = +0.5$	Therefore, make the phosphoric acid equivalent.
9–27–9	1, 3.0, 1.0	$Z(\text{i.e.})PK_1 - P_1K = 2.5 - 4.5 = -2.0$	

The tonnages containing the equivalent of phosphoric acid are as follows: Since

2.7 tons of 4–10–6 contain 10.8 27 16.2 units of N, P_2O_5, and K_2O, and
1 ton of 9–27–9 contains 9.0 27 9.0 units of N, P_2O_5, and K_2O,
the difference is 1.8 and 7.2 units of N and K_2O, and these amounts must therefore be added to 1 ton of 9–27–9 to make the equivalent of 2.7 tons of 4–10–6

NO-FILLER MIXTURES

A commercial mixer using any of these high analysis fertilizers as base materials would be interested in making no-filler mixtures. In no-filler mixing, problems of the following type will be encountered.

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ratios is a simple matter, and therefore it is only when X, Y, and Z are either positive or negative quantities that this algorithm is of value. The expressions determining the method of matching the ratios in these six cases, then, can be summarized as has been done in the above key.

For the suggestion and development of this algorithm the author is indebted to Professor C. N. Reynolds, Mathematics Dept., W. Va. University.

Problem III.—What materials, if any, must be added to a 15–30–15 fertilizer to make of it a ton of a fertilizer of the same ratio as 4–10–6? What would its analysis be? How much more concentrated would it be?

From Graph I it is apparent that phosphoric acid and potash must be added to make the 15–30–15 or 2.5–5–2.5 (C) the equivalent of a 4–10–6 or 2–5–3 (D). Since a no-filler fertilizer is desired, the total amount of the components is predetermined, i. e., 2,000 pounds. The number of combinations is therefore more limited in this case than is ordinarily so.

1 ton of 4–10–6 contains	80–200–120	pounds of N, P_2O_5, K_2O.
4/15 ton of 15–30–15 contains	80–160– 80	pounds of N, P_2O_5, K_2O.
Therefore, there are needed	0– 40– 40	pounds of P_2O_5, and K_2O.

Now since 4/15 of a ton is only 533.33 pounds, it is quite likely that an 8–20–12 instead of a 4–10–6 could be made by adding 80 pounds each of phosphoric acid and potash to 1,066.66 pounds of the 15–30–15. Thus, 2,000—1,066.66, or 933.34 pounds, must be the weight of the phosphoric acid and potash carriers containing the 80 pounds each of P_2O_5 and K_2O that are needed.

USE OF ALGEBRAIC METHODS

In solving for the needed amounts of the separate carriers, the use of some of the algebraic methods suggested by Beaumont and Knudsen (2) as here further developed will be a help in eliminating practically all of the trial and error.

Returning to Problem III, let P = number of pounds of needed P_2O_5 carriers of p percentage, or of carriers of average p percentage; and K = number of pounds of needed K_2O carrier of k percentage, or of carriers of average k percentage.

Since the number of algebraic equations obtainable are not sufficient for the solving of four unknowns, either p or k and consequently P or K, must first be evaluated. With the use of the various grades of superphosphate and kainit and muriate or sulfate of potash, mixtures with percentages of P_2O_5 between 16 and 45 and mixtures with percentages of K_2O between 12.5 and 50 can readily be obtained. Thus, if the values of p and k fall within these ranges, it makes no difference which one is first evaluated.

Therefore, if 16% superphosphate be used, then $p = 0.16$.
Then, since $Pp = 80$, $P = 500$.

The number of pounds of K_2O carriers needed then is 933.34—500, or 433.34 pounds. Since $Kk = 80$ and $K = 433.34$, then $k = 0.18$.

Therefore, the average percentage of the mixture of the K_2O carriers must be 18%. Such a mixture can be obtained by mixing muriate of potash and kainit.

Now, if $X =$ number of pounds of muriate and $Y =$ number of pounds of kainit, then $X+Y=433.34$, and $0.50X+0.125Y=80$, which makes $Y=364.3$ and $X=69.04$.

Checking, we find:

1,066.66 pounds of 15–30–15 carries..........	160	320	160
500.00 pounds of 16% superphosphate carries.		80	
364.30 pounds of 12.5% kainit carries.......			45.5
69.04 pounds of 50% muriate of potash carries			34.5
2,000.00	160	400	240.0

or the ingredients for a no-filler 8–20–12 fertilizer, which is one twice as concentrated as the 4–10–6.

DEVELOPMENT AND USE OF GENERAL ALGEBRAIC EQUATIONS FOR SOLVING FOR QUANTITIES IN NO-FILLER MIXTURES

Problems of the sort encountered in the mixing of fertilizers can be solved by the use of general equations. The general equation or formula, worked out by Beaumont and Knudsen (2) for their "solution 3," can not be used where a three-component material is selected as one of the ingredients. Their equation was adapted to a problem where nitrogen and phosphoric acid were added in single- and in double-component carriers to a potash base. The equation cannot be used without adaptation where combinations other than the above are desired. A truly general equation then would be of value. The following sets of equations, based on the same algebraic methods as those employed by Beaumont and Knudsen (2), but applicable through a much wider range of conditions, have been developed. The first set of these is designed for use in solving problems where the "base" and any of the other carriers are one-, two-, or three-component carriers. It is, however, restricted to cases where all of one of the nutrients is furnished by the base. The second set is designed for use in solving problems where all of one of the nutrients is not furnished by the base.

Development of the first set of equations.—If the general statement of conditions of problems, in which all of one of the nutrients is furnished by the "base," is tabulated as follows, then the derivation of the four linear equations given below becomes evident.

Kind of fertilizer carrier	Amount of carrier in pounds	Percentage composition of N	P_2O_5	K_2O	Pounds of nutrients of N	P_2O_5	K_2O
A	X	n_1	p_1	k_1	n_1X	p_1X	k_1X
B	Y	n_2	p_2	k_2	n_2Y	p_2Y	k_2Y
C	Z	n_3	p_3	k_3	n_3Z	p_3Z	k_3Z
D (base)	U	n_4	p_4	k_4	n_4U	p_4U	k_4U
Mixture	E (=2,000)	n_5	p_5	k_5	n_5E	p_5E	k_5E

Then:
$$\begin{aligned} n_1X+n_2Y+n_3Z &= n_5E-n_4U \\ p_1X+p_2Y+p_3Z &= p_5E-p_4U \\ k_1X+k_2Y+k_3Z &= k_5E-k_4U \\ X+Y+Z &= E-U \end{aligned}$$

When all the nitrogen is furnished by the "base" D.

There are three sets of values for X, Y, and Z, *viz.*, (a) when the "base" furnishes all of the nitrogen, (b) when it furnishes all of the phosphoric acid, and (c) when it furnishes all of the potash. The equation first developed is obtained by solving for X, Y, and Z (making use of determinants) under condition (a), that is, when $n_4U=n_5E$.

Then, if $\Delta = \begin{vmatrix} p_1 & p_2 & p_3 \\ k_1 & k_2 & k_3 \\ 1 & 1 & 1 \end{vmatrix}$

$$X=1/\Delta \begin{vmatrix} p_5E-p_4U & p_2 & p_3 \\ k_5E-k_4U & k_2 & k_3 \\ E-U & 1 & 1 \end{vmatrix};\quad Y=1/\Delta=\begin{vmatrix} p_1 & p_5E-p_4U & p_3 \\ k_1 & k_5E-k_4U & k_3 \\ 1 & E-U & 1 \end{vmatrix};$$

and $Z=1/\Delta \begin{vmatrix} p_1 & p_2 & p_5E-p_4U \\ k_1 & k_2 & k_5E-k_4U \\ 1 & 1 & E-U \end{vmatrix}$ provided $\Delta \neq 0$.

Therefore, (a) when $n_4U=n_5E$

$$X=\frac{E\,[p_5(k_2-k_3)+p_3(k_5-k_2)+p_2(k_3-k_5)]+U\,[k_4(p_2-p_3)+k_3(p_4-p_2)+k_2(p_3-p_4)]}{p_1(k_2-k_3)+p_2(k_3-k_1)+p_3(k_1-k_2)}$$

$$Y=\frac{E\,[p_5(k_3-k_1)+p_3(k_1-k_5)+p_1(k_5-k_3)]+U\,[k_4(p_3-p_1)+k_3(p_1-p_4)+k_1(p_4-p_3)]}{p_1(k_2-k_3)+p_2(k_3-k_1)+p_3(k_1-k_2)}$$

$$Z=\frac{E\,[p_5(k_1-k_2)+p_2(k_5-k_1)+p_1(k_2-k_5)]+U\,[k_4(p_1-p_2)+k_2(p_4-p_1)+k_1(p_2-p_4)]}{p_1(k_2-k_3)+p_2(k_3-k_1)+p_3(k_1-k_2)}$$

or $Z=E-(X+Y+U)$

and (b) When $p_4U=p_5E$, Substitute $n_1n_2n_3n_4n_5$ for $p_1p_2p_3p_4p_5$

and (c) When $k_4U=k_5E$, Substitute $n_1n_2n_3n_4n_5$ for $k_1k_2k_3k_4k_5$.

Solving Problem III by this method where the conditions are as follows:

Kind of fertilizer carrier	Amount of carrier in pounds	Percentage composition of N	P_2O_5	K_2O
Muriate..........	X	$n_1=0$	$p_1=0$	$k_1=0.50$
Kainit...........	Y	$n_2=0$	$p_2=0$	$k_2=0.125$
Superphosphate....	Z	$n_3=0$	$p_3=0.16$	$k_3=0$
Nitrophoska.......	U	$n_4=0.15$	$p_4=0.30$	$k_4=0.15$
Mixture..........	E=2,000	$n_5=0.08$	$p_5=0.20$	$k_5=0.12$

Since $n_4U = n_5E$, then $\frac{n_5E}{n_4} = U$, and $U = 533.3$ pounds if n_5 be 0.04.

Therefore n_5 can most likely be 0.08, and $U = 1066.6$.

By substituting in equations under (a)

$$X = \frac{4.14}{0.06} \text{ or } 69, \quad Y = \frac{21.86}{0.06} \text{ or } 364.3, \text{ and } Z = \frac{30.06}{0.06} \text{ or } 501.$$

Solving "Example 3" of Beaumont and Knudsen (2), it is found that

$$X = \frac{3.496}{0.02895} \text{ or } 120.8, \quad Y = \frac{18.288}{0.02895} \text{ or } 631.7, \text{ and } Z = \frac{22.32}{0.02895} \text{ or } 767.2,$$

which are the values they secured by the use of their equations. In their Example 3, tankage was added on the assumption that the inorganic materials present might by themselves make a mixture that would be unsatisfactory from a physical standpoint.

In case it is decided to add an organic carrier to the inorganic ones of Problem III, the amounts of the carriers may best be determined after the development of another set of equations.

Development of the second set of equations—The greatest number of materials likely ever to be used in a mixture is eight, *viz.*, high and low nitrogen carriers, high and low phosphoric acid carriers, high and low potash carriers, an organic material, and a "base," represented by S—Z, respectively. With a choice of eight materials practically any mixture (which of course contained more nutrients than the "base") can be made. The conditions are tabulated below:

Kind of fertilizer carrier	Amount of carrier in pounds	Percentage composition of			Pounds of nutrients of		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
A	S	n_1	p_1	k_1	n_1S	p_1S	k_1S
B	T	n_2	p_2	k_2	n_2T	p_2T	k_2T
C	U	n_3	p_3	k_3	n_3U	p_3U	k_3U
D	V	n_4	p_4	k_4	n_4V	p_4V	k_4V
E	W	n_5	p_5	k_5	n_5W	p_5W	k_5W
F	X	n_6	p_6	k_6	n_6X	p_6X	k_6X
G	Y	n_7	p_7	k_7	n_7Y	p_7Y	k_7Y
H	Z	n_8	p_8	k_8	n_8Z	p_8Z	k_8Z
Mixture	E	n_9	p_9	k_9	n_9E	p_9E	k_9E

In this case four equations are again possible, as:

$$\begin{aligned}
n_1S+n_2T+n_3U+n_4V+n_5W+n_6X+n_7Y+n_8Z&=n_9E\\
p_1S+p_2T+p_3U+p_4V+p_5W+p_6X+p_7Y+p_8Z&=p_9E\\
k_1S+k_2T+k_3U+k_4V+k_5W+k_6X+k_7Y+k_8Z&=k_9E\\
S+T+U+V+W+X+Y+Z&=E.
\end{aligned}$$

Since it is possible to solve for no more than four unknowns when only four equations are given, it is necessary to arrange the equations so that four of the unknowns may be solved in terms of the others, as

$$\begin{array}{l}
n_1S+\dots\dots+n_4V=n_9E-(n_5W+\dots\dots+n_8Z)\\
p_1S+\dots\dots+p_4V=p_9E-(p_5W+\dots\dots+p_8Z)\\
k_1S+\dots\dots+k_4V=k_9E-(k_5W+\dots\dots+k_8Z)\\
S+\dots\dots+V=E-(W+\dots\dots+Z).
\end{array}$$

S, T, U, and V may be determined provided values are assigned to W, X, Y, and Z. However, in problems such as these, W, X, Y, and Z must be assigned reasonable values or be equal to zero in order that the values of S, T, U, and V be not negative.

If for simplification of the following equations

$$\begin{array}{l}
n_9E-(n_5W+n_6X+n_7Y+n_8Z)=A\\
p_9E-(p_5W+p_6X+p_7Y+p_8Z)=B\\
k_9E-(k_5W+k_6X+k_7Y+k_8Z)=C\\
E-(W+X+Y+Z)=D,
\end{array}$$

then the values[7] for S, T, U, and V, as solved by determinants, are the following:
Where

$$\Delta=\left\{\begin{array}{l}
n_1[p_2(k_3-k_4)+p_3(k_4-k_2)+p_4(k_2-k_3)]-p_1[n_2(k_3-k_4)+n_3(k_4-k_2)\\
+n_4(k_2-k_3)]+k_1[n_2(p_3-p_4)+n_3(p_4-p_2)+n_4(p_2-p_3)]-n_2(p_3k_4-\\
p_4k_3)-n_3(p_4k_2-p_2k_4)-n_4(p_2k_3-p_3k_2)
\end{array}\right.$$

$$S=\frac{\begin{array}{l}
1/\Delta\ \{A[p_2(k_3-k_4)+p_3(k_4-k_2)+p_4(k_2-k_3)]-B[n_2(k_3-k_4)+\\
n_3(k_4-k_2)+n_4(k_2-k_3)]+C[n_2(p_3-p_4)+n_3(p_4-p_2)+n_4(p_2-p_3)]-\\
D[n_2(p_3k_4-p_4k_3)+n_3(p_4k_2-p_2k_4)+n_4(p_2k_3-p_3k_2)]\}^{*}
\end{array}}{\Delta}$$

$$T=\frac{\begin{array}{l}
1/\Delta\ \{-A[p_1(k_3-k_4)+p_3(k_4-k_1)+p_4(k_1-k_3)]+B[n_1(k_3-k_4)+\\
n_3(k_4-k_1)+n_4(k_1-k_3)]-C[n_1(p_3-p_4)+n_3(p_4-p_1)+n_4(p_1-p_3)]+\\
D[n_1(p_3k_4-p_4k_3)+n_3(p_4k_1-p_1k_4)+n_4(p_1k_3-p_3k_1)]\}
\end{array}}{\Delta}$$

$$U=\frac{\begin{array}{l}
1/\Delta\ \{A[p_1(k_2-k_4)+p_2(k_4-k_1)+p_4(k_1-k_2)]-B[n_1(k_2-k_4)+\\
n_2(k_4-k_1)+n_4(k_1-k_2)]+C[n_1(p_2-p_4)+n_2(p_4-p_1)+n_4(p_1-p_2)]-\\
D[n_1(p_2k_4-p_4k_2)+n_2(p_4k_1-p_1k_4)+n_4(p_1k_2-p_2k_1)]\}
\end{array}}{\Delta}$$

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*The formulae appear to require altogether too much work for solution to be valuable, but in most cases it will be found that the greatest portion of the formulae (of course, various portions in various cases) fall out, since they are equal to zero, as in solution of problem III:

$$S=\frac{137.5\,[.2(.5-.125)+0+0]-387.5\,[0+0+0]+240\,[0+0+0]-1750\,[0+0+0].}{.15\,[.2(.5-.125)+0+0]-.3\,[0+0+0]+.15\,[0+0+0]-0-0-0}$$

[7] S, T, U, and V can be one-, two-, or three-component materials, but together they must carry all three of the nutrients, N, P_2O_5, and K_2O.

$$V = \frac{1/\Delta \ \{-A[p_1(k_2-k_3)+p_2(k_3-k_1)+p_3(k_1-k_2)]+B[n_1(k_2-k_3)+n_2(k_3-k_1)+n_3(k_1-k_2)]-C[n_1(p_2-p_3)+n_2(p_3-p_1)+n_3(p_1-p_2)]+D[n_1(p_2k_3-p_3k_2)+n_2(p_3k_1-p_1k_3)+n_3(p_1k_2-p_2k_1)]\}}{\Delta}$$

Solving Problem III where the conditions are:

Nitrophoska	S	$n_1=0.15$	$p_1=0.30$	$k_1=0.15$
Superphosphate	T	$n_2=0$	$p_2=0.20$	$k_2=0$
Muriate	U	$n_3=0$	$p_3=0$	$k_3=0.50$
Kainit	V	$n_4=0$	$p_4=0$	$k_4=0.125$
Tankage	W	$n_5=0.09$	$p_5=0.05$	$k_5=0$
Mixture	E	$n_9=0.08$	$p_9=0.20$	$k_9=0.12$

In this case X, Y, and Z are each equal to zero. W must be assigned a reasonable value, such as 250 pounds.

Then, $A=n_9E-n_5W$ or $160-0.09\times250$ or 137.5
$B=p_9E-p_5W$ or $400-0.05\times250$ or 387.5
$C=k_9E-k_5W$ or $240-0$ or 240.0
and $D=E-W$ or $2{,}000-250$ or $1{,}750.0$

Substituting the proper values, then

$$S=\frac{10.3125}{0.01125} \text{ or } 916.67,\ T=\frac{6.328125}{0.01125} \text{ or } 562.50,\ U=\frac{2.059375}{0.01125} \text{ or } 183.05,$$

$$\text{and } V=\frac{0.9875}{0.01125} \text{ or } 87.77.$$

For proof we have:

			N	P_2O_5	K_2O
Nitrophoska	S	916.67	137.5	275.0	137.50
Superphosphate	T	562.50		112.5	
Muriate	U	183.05			91.53
Kainit	V	87.78			10.97
Tankage	W	250.00	22.5	12.5	
		2,000.00	160.0	400.0	240.00

VALUE OF THE ALGEBRAIC EQUATIONS

The solution of fertilizer problems by the sole use of algebraic equations, such as those here developed, entails a set of calculations which is greater than that which is required by the arithmetical method. This is, however, more the case in solving problems dealing with filler mixtures than in those dealing with no-filler mixtures.

The equations should be used merely to eliminate the trial and error procedure of the arithmetical method. If an equation is used only to determine the required quantity of one of the carriers in the no-filler mixture, the required quantities of the other carriers may, n many cases, be solved very easily. Especially is this true if the quantity of the carrier containing the greatest number of different elements is first determined by an algebraic equation. This is illustrated by the following example which is extremely simple when worked as here suggested.

Solving Problem III (where the 250 pounds of tankage are added)

$$\text{Nitrophoska, S (by algebraic equation)} = \frac{10.3125}{0.01125}, \text{ or } 916.67$$

$$\text{Superphosphate} = [400 - (0.30 \times 916.67 + 0.05 \times 250)] \div 20, \text{ or } 562.495$$
$$\text{Muriate} + \text{kainit} = 2{,}000 - (916.67 + 562.495 + 250), \text{ or } 270.834$$

Then, since $M + K = 270.834$ and $0.50M + 0.125K = 240 - (0.15 \times 916.67)$, or 102.5, muriate $= 183.05$ and kainit $= 87.78$, as obtained before.

SUMMARY

Attention is called to the fact that a number of extra high analysis complete fertilizers are now being marketed, and that most of them do not fit into the fertilizer triangle scheme.

The mixing of these extra high analyses fertilizers with either fertilizing or non-fertilizing materials to change them into mixtures of the analyses more commonly demanded or into mixtures that are the equivalent of these is an operation already being carried out by commercial mixers.

Formulae for determining both the kinds and the amounts of materials needed in such changes have been developed.

The use of these formulae simplify considerably the mathematical operations, especially in the solving of no-filler mixtures, if they are used merely to eliminate the trial and error of the mathematical method and not for the complete solution.

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THE EFFECT OF MANGANESE, COPPER, ZINC, BORON, AND ARSENIC ON THE GROWTH OF OATS[1]

J. S. McHargue and O. M. Shedd[2]

A number of investigations (1–7)[3] have been published in recent years which indicate that more than 10 elements are necessary factors for the normal growth and maturation of plants. In previous reports the senior author and co-workers have demonstrated the necessity of manganese and copper in the economy of plants and animals. The purpose of the experiments reported in this paper was to confirm previous findings and to obtain additional evidence concerning the necessity of small amounts of other elements in the economy of plants. To this end, oat plants were grown to maturity in purified sand cultures carried on at the Kentucky Agricultural Experiment Station during the spring and summer of 1928.

The sand cultures were prepared as follows: Fine quartz sand of uniform grain was washed in running tap water to remove a small amount of clay and fine silt, after which the sand was digested in a mixture of HCl and HNO_3 acids in large porcelain dishes over boiling water to remove the coating of iron and manganese oxides which adhered to the grains. After digesting in hot acids for several hours, the sand was washed with clear tap water and then rinsed with distilled water until free of chlorides. Upon drying, snow-white sand composed of grains of quartz was thus obtained from which the sand cultures were made by the addition of the appropriate chemical compounds.

The basal plant nutrient ration which was added to each of the pots of purified sand contained the amounts indicated of the following chemical compounds:

2 grams of $CaCO_3$
3 grams of $Ca\ (NO_3)_2 4H_2O$
5 grams of KH_2PO_4
3 grams of KNO_3
2 grams of $MgSO_4,7H_2O$
1 gram of KCl

These chemicals were of high purity and did not contain more than traces of any of the elements which were to be tried. Each pot,

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[2] Research Chemist and Acting Head of Department and Research Chemist, respectively.

[3] Reference by number is to "Literature Cited," p. 746.

the original weight of which was known, contained 8,000 grams of dry, purified sand which was mixed with the basal plant nutrient ration and enough pure hydrous ferric oxide to give the sand a distinct brownish red color. The experiments were carried out in duplicate, two pots each receiving the following treatments:

Pots Nos. 1 and 2, checks, basal plant nutrients only
Pots Nos. 3 and 4, B.P.N.*+1 gram $MnCO_3$
Pots Nos. 5 and 6, B.P.N.*+1 gram $MnCO_3$+0.5 gram CuO
Pots Nos. 7 and 8, B.P.N.*+1 gram $MnCO_3$+0.5 gram CuO+0.25 gram $ZnCO_3$
Pots Nos. 9 and 10, B.P.N.*+1 gram $MnCO_3$+0.5 gram CuO+0.25 gram $ZnCO_3$+0.1 gram H_3BO_3
Pots Nos. 11 and 12, B.P.N.*+1 gram $MnCO_3$+0.5 gram CuO+0.25 $ZnCO_3$+0.1 gram H_3BO_3+0.1 gram As_2O_3
Pots Nos. 13 and 14, B.P.N.*+0.7564 gram powdered pyrolusite, (MnO_2), containing almost the same quantity of Mn as in the other pots. The pyrolusite was a commercial sample and contained small quantities of copper, zinc, barium, nickel, and cobalt.

*B. P. N. = Basal plant nutrients.

The mineral plant nutrients were thoroughly mixed by hand with the proper quantity of sand in a large porcelain dish and the mixture was put into jars of acid-proof stoneware. Enough distilled water was added to each to bring the sand to about two-thirds saturation and the oat seeds were planted. After the seedlings were up and at the proper stage of growth they were thinned to 15 strong plants to each pot. The pots were subsequently weighed at regular intervals and distilled water added to restore that lost by transpiration and evaporation. The experiments were carried on in the greenhouse until the oat plants attained maturity. Photographs were made previous to and at the time of harvesting the oat plants.

The reaction of the sand cultures was tested on March 21, April 3, and May 25, 1928, and the pH readings on seven of the pots at these dates averaged 7.2, 7.02, and 7.6, respectively, which shows that the plants made their growth in a neutral or slightly alkaline medium.

In Fig. 1 only one of the pots in each treatment is shown. The plants in the duplicate pots attained a similar growth except in the remaining check pot which did not make as much growth as the check shown. The difference in the growth of the plants in the check pots is shown strikingly in Fig. 3. The bunch of oat heads labeled No. 1 in this photograph contains the heads that grew on the plants labeled No. 1 in Fig. 1, and the smaller bunch of heads labeled No. 2 in Fig. 3 contains the heads produced in the other check pot.

Fig. 2 shows the results obtained with pyrolusite (MnO_2) as the source of Mn. Pot No. 1 is the same check pot as shown in Fig. 1 from which Mn was excluded as nearly as possible. The purpose of this experiment was to ascertain if the rather sparingly soluble pyrolusite (MnO_2) could be used as a source of Mn for agricultural purposes. From the results obtained in this experiment, oats apparently can utilize pyrolusite as a source of Mn, although it will be seen in Table 2 that less manganese was assimilated by the plants that grew in the cultures to which pyrolusite was added than in those to which $MnCO_3$ was added.

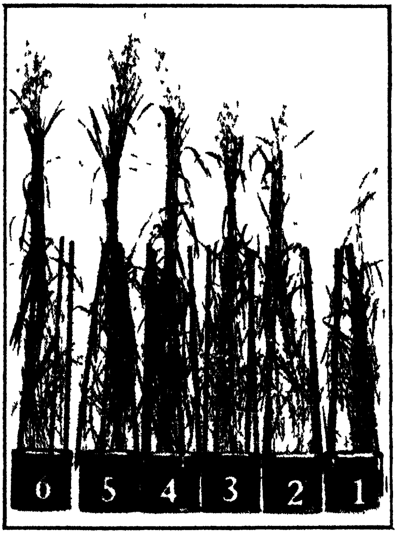

Fig. 1.—1, basal plant nutrients only, check; 2, basal treatment plus Mn; 3, basal treatment plus Mn and Cu; 4, basal treatment plus Mn,Cu, and Zn; 5, basal treatment plus Mn, Cu, Zn, and B; and 6, basal treatment Cu, plus Mn, Cu, Zn, B, and As.

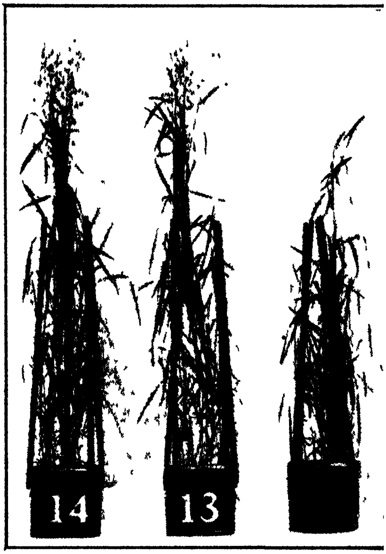

Fig. 2.—Pot 1, check, basal plant nutrients only; pots 13 and 14, basa treatment plus pyrolusite (MnO_2).

TABLE 1.—*Yields of straw and grain of oats.*

Treatments	Straw Weight, grams	Straw Increase %	Grain Weight, grams	Grain Increase %
No Mn	49	—	1.27	—
Mn	72	47	22.34	1,659
Mn+Cu	75	53	28.37	2,134
Mn+Cu+Zn	81	65	24.45	1,825
Mn+Cu+Zn+B	85	73	22.06	1,637
Mn+Cu+Zn+B+As	80	63	15.97	1,157
MnO_2	75	53	33.62	2,547

Fig. 3 shows the heads of the oats grown in each pot in the experiment. The heads numbered 1 and 2 are from the check pots.

At maturity, the plants were harvested and allowed to air-dry. The straw and grain from each pot were weighed separately. The total weights of straw and of grain produced in the two pots of each treatment and the percentage of increase in yields are given in Table 1.

From the results shown in Table 1 it is to be observed that there was a gradual increase in the yield of the straw with the addition of Mn, Cu, Zn, and B, with the maximum yield of straw occurring in the B cultures. The addition of As caused a diminution in the yield of straw, although the yield was still 7% more than in the cultures to which $MnCO_3$ alone was added.

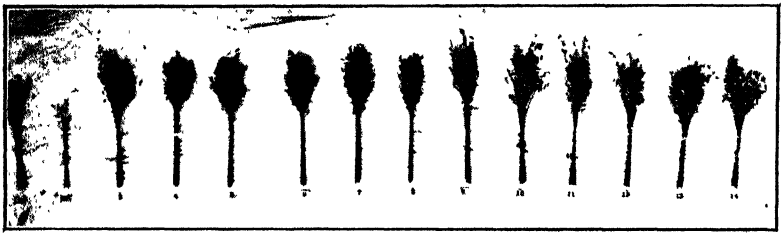

FIG. 3.—The mature heads of the oats that grew in each of the cultures.

In one of the check cultures only 1.27 grams of grain was produced and none in the other. With the addition of Mn in treatment No. 2 the very remarkable gain of 21.07 grams of grain, equivalent to 1,659% increase over the productive check, was obtained, which is attributable to the addition of Mn alone. With the addition of Mn and Cu there was an increase of 27.1 grams of grain over the check, equivalent to 2,134%. The increase over treatment No. 2 attributable to Cu in the Mn and Cu combination was 27%. With the cultures containing Mn, Cu, and Zn a yield of 23.18 grams over the check was produced which is 13.8% less than the yield of grain produced in the Mn and Cu cultures but still an increase of 9.4% over Mn alone. The addition of B decreased the yield of grain in comparison with all the previous treatments, but the yield in the B culture was only a little less than that from the Mn treatment alone. The addition of As resulted in a marked diminution in the yield of grain and a smaller diminution in the yield of straw, the latter being slightly more than that from the Mn alone.

In the pyrolusite cultures the largest yield of grain of all the treatments was produced. However, the yield of straw that produced the largest yield of grain was 11.7% less than the maximum yield of straw, thus indicating that a maximum grain yield does not necessarily mean a maximum yield of straw and *vice versa.*

The yield of straw in the duplicate pots was ample to permit a rather complete analysis. For the analytical work the straw from each pair of pots of each treatment was made into a composite sample representing that treatment. The same procedure was followed with the grain. The analytical results are given in Table 2.

TABLE 2.—*Analyses of oat straw and manganese determinations and tests for copper in the grain, computed to the moisture-free condition.*

	Treatments						
	No Mn %	Mn %	Mn, Cu %	Mn, Cu, Zn %	Mn, Cu, Zn, B %	Mn, Cu, Zn, B, As %	MnO_2 %
Crude ash......	23.61	21.96	20.09	20.43	19.64	20.71	19.34
Si.............	3.66	3.08	2.45	2.70	2.35	2.37	2.39
Fe............	0.0370	0.0318	0.0251	0.0190	0.0125	0.0249	0.0063
Mn...........	0.0004	0.0644	0.0858	0.1167	0.1383	0.1382	0.0047
Cu...........	0.0027	0.0035	0.0054	0.0024	0.0020	0.0012	0.0007
Zn...........	0.0041	0.0067	0.0042	0.0193	0.0151	0.0101	0.0066
Ca...........	0.37	0.57	0.64	0.61	0.67	0.62	0.55
Mg...........	0.46	0.48	0.48	0.48	0.50	0.54	0.39
P.............	0.79	0.94	0.80	0.85	0.87	1.08	0.72
K.............	7.35	7.00	6.64	6.62	6.56	6.33	6.93
Na...........	0.22	0.22	0.35	0.38	0.41	0.35	0.27
S.............	0.50	0.35	0.51	0.41	0.46	0.47	0.35
N.............	2.33	1.01	0.81	1.07	0.93	1.06	0.70
Protein, (Nx6.25).....	14.58	6.34	5.06	6.70	5.84	6.62	4 36
			Grain				
Mn	none	0.0117	0.0124	0.0179	0.0185	0.0235	0.0037
Cu............	none	trace	trace	trace	trace	trace	none

The amount of grain produced was sufficient in all the experiments, except the checks, to permit Mn determinations and tests for Cu. The results are included in Table 2.

The analyses of the straw and grain in Table 2 present a number of interesting points which are worthy of comment. The largest percentage of crude ash occurred in the straw of the check cultures. There was an appreciable diminution in the ash of the straw that grew in the cultures to which $MnCO_3$ alone was added, and a still greater diminution in the ash content of the straw that grew in the cultures to which Cu was added also, after which the ash content remains approximately constant. The same relation maintains with respect to Si and Fe, except in the MnO_2 cultures (Nos. 13 and 14) in which the Fe taken up is much less than in the check cultures.

The amount of Mn assimilated by the straw that grew in the different cultures is of particular interest. From the percentage of Mn found in the straw of the check cultures, it is evident that we were successful in reducing the Mn to a very low concentration. In the straw where $MnCO_3$ alone was added, the amount taken up was more than 160 times as much as was found in the check straw. The addition of Cu, Zn, and B, respectively, caused a marked increase in the amount of Mn assimilated which remained constant with the addition of As. However, where MnO_2 was the only source of Mn, the amount of this element found in the straw was approximately one-thirtieth as much as was found in the experiment to which As was added.

The percentage of Mn found in the grain produced in the pots with different treatments shows a gradual increase and attains the maximum in the cultures to which As was added. These pots contained the most complex mineral mixture. The grain produced in the pots containing MnO_2 contained approximately one-sixth as much Mn as the maximum found in the grain from the other treatments.

The amount of Cu contained in the straw produced in the check cultures indicates that this element was not very well controlled in the experiment. The Cu determinations show considerable variations. The maximum amount of Cu found was in the plants from the Mn-Cu treatment; the remaining plants showing a gradual diminution in the amount assimilated. The plants that grew in the cultures containing As show a Cu content of about one-third that of the check plants. The plants that grew in the cultures to which pyrolusite (MnO_2) was added contained approximately one-fourth as much Cu as the check plants.

The Zn content of the check plants shows that this element was not well controlled in the experiments. However, the straw that grew in the cultures to which Zn was added had a Zn content of about four times as great as the straw that grew in the cultures to which no Zn was added. The Zn content of the straw that grew in the cultures to which pyrolusite was added was only a little more than the average Zn content of the straw that grew in cultures to which no Zn was added, i. e., pots 1, 2 and 3, thus indicating that possibly the plants that grew in cultures 1, 2, and 3 obtained all the Zn necessary for their growth from some unknown source.

The Ca and Mg content of the straw shows no marked variations and this statement is true of P, except in the cultures to which As was added. In this experiment a marked increase is shown in the P content.

The amount of K assimilated is large in all of the experiments. The maximum K content occurred in the check plants after which there was a gradual diminution in the K content of the other experiments in the series, except the straw that grew in the cultures to which MnO_2 was added. In these cultures the amount of K assimilated was approximately as much as in the check plants. This result for K is in contrast to what occurred with the other elements thus far mentioned in this experiment and probably has some significance which is not apparent at this time.

The N content of the check plants is more than twice as much as in any other one lot of the straws receiving treatments and more than three times as much as in the straw that grew in the cultures to which MnO_2 was added. In the check plants the K and N are both high, whereas in the MnO_2 experiment the K is nearly as much as in the check plants, but the N is only about one-third as much as in the check plants.

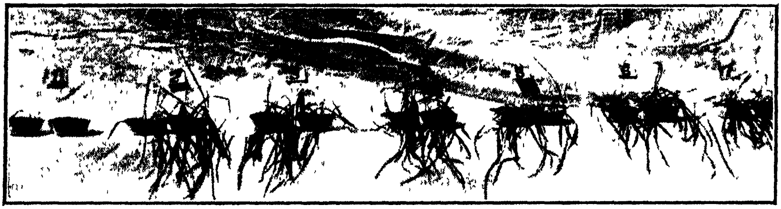

FIG. 4.—Germination of seed from plants receiving different treatments. (See Table 3.)

Enough seeds were reserved from the grain produced in each of the sand cultures to test their viability. The seeds were planted in moist sand in small porcelain dishes and kept in the laboratory for a few weeks. The results of the tests are shown in Fig. 4, and in Table 3.

TABLE 3.—*Germination tests made on the oat seeds produced in each of the treatments.*

No.	Treatment	Percentage of germination
1	Check	90 and *
2	Mn	70 and 100
3	Mn+Cu	80 and 90
4	Mn+Cu+Zn	100 and 100
5	Mn+Cu+Zn+B	100 and 60
6	Mn+Cu+Zn+B+As	100 and 100
7	MnO_2	90 and 100

*No seed produced.

One of the check cultures produced a few seeds with a viability of 90%, but they failed to make any appreciable growth after germination. In the Mn and Mn + Cu cultures the average germination was 85% each. With the addition of Zn each of the cultures produced seeds having 100% viability which probably has some significance in regard to the necessity of this element in the production of viable seeds. The addition of B to the treatments gave an average viability of 80%. The addition of As produced seeds having an average viability of 100%, and pyrolusite (MnO_2) gave an average viability of 95%. The failure of the seeds produced in one of the check cultures to make any appreciable growth after germination emphasizes the importance of seeds containing enough Mn to produce vigorous seedlings.

SUMMARY

Oats grown in purified sand cultures to which small amounts of compounds of Mn, Cu, Zn, B, and As were added produced very marked increased yields in comparison with the checks. However, when compared with the Mn treatments, Cu and Zn gave additional increases in the yield of grain and straw. The addition of B gave an increase in the yield of straw but a decrease in the yield of grain when compared with the Mn treatment.

With the addition of As an increase in the yield of straw as compared with Mn alone was maintained, but a decided diminution in the yield of the grain resulted.

Pyrolusite (MnO_2) added to a basal plant nutrient culture produced the maximum yield of grain but not the largest yield of straw.

A complete mineral analysis of the ash of the straw produced in each of the cultures gave some interesting relations in regard to the assimilation of the different elements. From the results obtained in this experiment it is to be assumed that Mn, Cu, Zn, and possibly B are important factors in the growth of oats.

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A COMPARISON OF THE HYDROMETER METHOD AND THE PIPETTE METHOD FOR MAKING MECHANICAL ANALYSIS OF SOILS, WITH NEW DIRECTIONS[1]

George John Bouyoucos[2]

A comparison has been made between the hydrometer method and the pipette method and it has been found that what the pipette method determines as clay (0.005-000 mm) and the finer clay (0.002-000 mm), the hydrometer method will determine in 1 and 2 hours, respectively, even though theoretically it should take a much longer time. This comparison has been checked by the United States Bureau of Chemistry and Soils, and the results obtained go to show that the two methods agree very closely with few exceptions. It would seem, therefore, that the hydrometer method can be used with confidence for making mechanical analysis of soils for all practical purposes.

The final procedure as developed up to date for making mechanical analysis of soils by the hydrometer method, is as follows: Add 50 grams of the fine textured soils and 100 grams of the sand, based on oven-dry condition, to the dispersing cup. Fill the cup with distilled water to about 1½ inches from the top. Add to the contents 5 cc of a solution of saturated and filtered sodium oxalate and 5 cc normal sodium hydroxide. If the soil is in lumps, sufficient time must be given to it to slake and to soak. As a matter of fact, it is well to allow all soils to soak for about 15 minutes before dispersing them. The soils should always be air dry, because in the wet condition they do not slake. The soaking can be done in a separate vessel and the material then washed into the cup. Then connect the cup to the stirring motor, and stir the contents for 5 minutes in the case of sands, and 10 minutes in the case of all other soils. Those soils, however, which are recognized as difficult of dispersion should be dispersed for 20 to 30 minutes, or longer. The sands should not be stirred more than 5 minutes because they seem to undergo grinding.

Pour and wash the contents into the special cylinder. If 50 grams of soil are used, fill the cylinder up to the lower mark with the hydrometer in it. If 100 grams of soil are used, fill it to the upper mark with the hydrometer in it. Only distilled water should be used. Then take the hydrometer out, place the palm of one hand on the mouth of the cylinder and shake the contents vigorously, turning the cylinder upside down and back several times. Place the cylinder quickly on the table and note the time immediately. Then at the desired period put the hydrometer in the suspension column, record the reading, and then take it out again. There is a tendency for slight amounts of soil material to settle on the shoulder of the hydrometer, and it is better not to leave it in continuously for all readings. Each time the hydrometer is used it should be clean.

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[1] Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Received for publication June 16, 1930.

[2] Research Professor in Soils.

At every hydrometer reading the temperature of the suspension should be measured. Great care must be taken, however, not to disturb too much the suspension column in putting in and taking out the hydrometer and the thermometer. For every 1°F above or below 67°F apply a temperature correction of 0.2 graduation on the hydrometer. This temperature correction, however, is only an approximation, as it tends to vary somewhat with extreme concentrations of soil suspensions and also with extreme variations of temperature. Probably, the most accurate hydrometer readings are taken near the temperature of 67°F which is the temperature at which the hydrometer was calibrated in actual soil suspensions. Extreme temperatures such as 100°F and 50°F should be avoided. If possible temperatures should be above 67°F rather than below. For temperatures above 67°F the corresponding amount of correction is added to the hydrometer reading, and for temperatures below 67°F the corresponding amount is subtracted. The corrected hydrometer reading, which represents grams per liter of water, is then divided by the weight of soil taken and multiplied by 100, the result being the percentage of material still in suspension.

In case of soils which tend to floculate after receiving the sodium oxalate and sodium hydroxide treatment, the following procedures should be tried: (1) Add separately to the same sample more than 5 cc of sodium oxalate and sodium hydroxide. (2) If this fails, use a new sample and do not add any reagent. (3) If the soil still persists in floculating, wash it and add a mixture of the reagent.

As stated in a former communication, the hydrometer method cannot subdivide the sands into their various fractions, but can only determine their combined or total amount. Various experimental tests seem to show that the total combined sands of a soil can be ascertained most accurately by taking a hydrometer reading at the end of 40 seconds. A correct reading can be easily made in this short period except in some organic soils which have a tendency to produce froth on the top of the column after shaking, in which case a correct hydrometer reading is not always possible. One way to overcome this difficulty is to blow at the froth when it tends to disappear quickly. The determination of the combined sand should be considered only as approximately correct.

As stated in previous papers, the hydrometer was calibrated against actual soil suspensions, consisting of an average loam soil. Its readings, therefore, are quite accurate. It was found very difficult to calibrate the range from 0 to 10 grams per liter, however, and this range is not so accurate as the rest of the range. This range reads about 1 gram per liter too high. It is advisable, therefore, to subtract 1 gram per liter from all hydrometer readings below 9.9 grams per liter before correcting for temperature.

A unique feature of the hydrometer method is the fact that the personal element is reduced to a minimum. One cannot but obtain correct results if one watches for one important thing, namely, the paddle to the stirring rod. Practically the whole success of the hydrometer method, as it is with all mechanical analysis methods, depends upon a complete dispersion of the soil, and a complete dispersion can only be obtained when the paddle on the stirring rod is in proper condition. On long stirring and especially with sandy soils, this paddle tends to wear out and become flat and small. In this condition its efficiency is practically gone and the soils are not properly dispersed, consequently the results are not correct. It cannot be emphasized too strongly, therefore, that the first concern of the operator who uses the hydrometer method is always to watch the stirrer. It is well to have an extra supply of new stirrers, so that the old ones can be easily replaced when necessary, or a paddle of hard steel can be placed on the stirrer. But by all means the paddle should not be neglected if reliable results are desired.

Another extremely important thing to watch for is that the cup should have baffles in it. Without the baffles the soils cannot be dispersed easily.

To calculate the conventional amount of combined sand (1.0–0.05), silt (0.05–0.005 mm), and clay (0.005–000 mm) and the finer clay (0.002–000 mm) as determined by the hydrometer method, the following procedure is followed:

The corrected hydrometer reading at the end of 40 seconds is divided by the amount of soils taken and multiplied by 100. The result is percentage of material still in suspension at the end of 40 seconds. This percentage is subtracted from 100 and the result is the percentage of material that settled out at the end of 40 seconds, which is supposed to represent all the sand in the soil. The corrected hydrometer reading at the end of 15 minutes is also divided by the amount of soil and multiplied by 100. The result is the percentage of material still in suspension and is considered to be the "total colloidal content of soils." The corrected hydrometer reading at the end of 1 hour is also divided by the amount of soil sample and multiplied by 100. The result is percentage of material still in suspension and is considered to be the conventional clay (0.005–000 mm). The percentage of the conventional silt is obtained by subtracting the clay from 100, and from this result subtracting again the percentage of sand. To obtain the finer clay (0.002–000 mm), it is only necessary to divide the corrected hydrometer reading at the end of two hours by the weight of the soil sample and multiply by 100. The organic matter content and the carbonate content, are not determined by the method.

It is thus seen that by means of the hydrometer method almost a complete mechanical analysis of soils can be made in only 1 or 2 hours, with very little work or effort.

From all studies and examinations thus far made, it seems that the hydrometer method is more of a quantitative method and that it is reliable on all soils that are properly dispersed and properly stabalized by the reagent. It seems to be especially accurate in the clay fraction (0.005 mm). In the finer clay portion (0.002 mm) it may not be so accurate in some soils that have a very large amount of their finer material just slightly above the 0.002 mm size. In such soils the hydrometer method indicates a larger content of the 0.002 mm fraction than the pipette method, but the differences may not be more than 10%.

In peats and mucks the hydrometer method is not very reliable, first, because these materials are almost impossible to disperse, and second, because they have a smaller specific gravity and the hydrometer was calibrated on average normal loam soils. The method, however, seems to be quite accurate on mineral soils containing relatively high organic matter content, providing the latter is well decomposed, and is completely dispersed.

In the case of very alkali soils, it is advisable to wash them before using for analysis, or a correction applied for the salts if appreciable in amounts.

The soil material which the hydrometer method determines at the end of 15 minutes standing and which has been designated as the "total colloidal content of soils" seems to have the greatest importance from a practical or agricultural standpoint. This "total colloidal content" corresponds to the heat of wetting results and takes into account the organic matter and the activity of the soil material. It further shows a much closer relationship with various physical characteristics of soils than either the 0.005 mm or 0.002 mm fractions.

By taking hydrometer readings continuously or every so often, a complete distribution curve of size particles of soils and their respective amounts can be readily and quite reliably obtained.

The hydrometer method, therefore, would seem to give most, if not all, the essential information required for all practical purposes, and considering its great rapidity, simplicity, efficiency, and reasonable accuracy, it should meet a great need.

It should be clearly borne in mind that in view of the tremendous physico-chemical variations that exist in the different soils, no one method, whether it be the hydrometer method or the pipette method, can be expected to be ideal for all types of soil, especially when a standardized procedure must be followed for all soils.

The dispersing machine with the cup used in this method is handled by the Hamilton Beach Mfg. Co., Racine, Wisconsin; while the hydrometer and special cylinder are handled by the Taylor Instrument Co., Rochester, New York.

NOTE

THE KANSAS WHEAT BELT PROGRAM

The agronomy extension program of the wheat belt of Kansas has been conducted as a part of the five-year Kansas wheat belt program (Fig. 1) since 1925. Earlier efforts in agronomy extension work with wheat in this area indicated that an effort to get the farmer to free his wheat fields of rye were fruitless unless the grain buyer made a differentiation against rye-mixed wheat, which many did not do. Cooperation was therefore sought with the marketing specialist to urge buying wheat on a grade basis. Like cooperation was sought with the plant pathologist and marketing specialist as an inducement to reduce the amount of smut. The agronomist and entomologist found it necessary to cooperate on a tillage program which would conserve moisture and at the same time control insects. The result was the five-year Wheat Belt Program which is a coordination of agronomy, disease control, insect control, and marketing programs.

Results have proved the desirability of this move. The amount of good seed wheat that changed hands during the four years prior to the organization of this program was 790,000 bushels, or almost 200,000 bushels per year. During the four years of the Wheat Belt Program now past, the amount of good seed changing hands was 1,931,000 bushels, almost 500,000 bushels each year.

In 1929, 77% of the wheat land was plowed by August first in the area which had been conducting this program for four years, while only 32% of the wheat land outside this area had been plowed by that date.

County agents' reports indicated 66,849 acres of fallow and partial fallow the first year of the program (1926) and 185,761 acres in 1929.

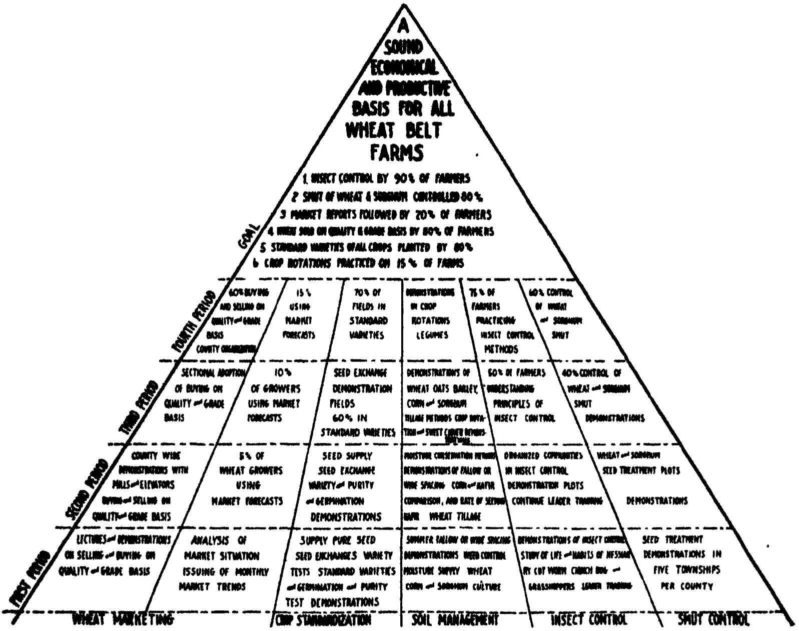
A SOUND ECONOMICAL AND PRODUCTIVE BASIS FOR ALL WHEAT BELT FARMS
1 INSECT CONTROL BY 90% OF FARMERS
2 SMUT OF WHEAT & SORGHUM CONTROLLED 80%
3 MARKET REPORTS FOLLOWED BY 20% OF FARMERS
4 WHEAT SOLD ON QUALITY & GRADE BASIS BY 80% OF FARMERS
5 STANDARD VARIETIES OF ALL CROPS PLANTED BY 80%
6 CROP ROTATIONS PRACTICED ON 15% OF FARMS
GOAL
FOURTH PERIOD
60% BUYING AND SELLING ON QUALITY and GRADE BASIS COUNTY ORGANIZATION
15% USING MARKET FORECASTS
70% OF FIELDS IN STANDARD VARIETIES
DEMONSTRATIONS IN CROP ROTATIONS LEGUMES
75% OF FARMERS PRACTICING INSECT CONTROL METHODS
60% CONTROL OF WHEAT and SORGHUM SMUT
THIRD PERIOD
SECTIONAL ADOPTION OF BUYING ON QUALITY and GRADE BASIS
10% OF GROWERS USING MARKET FORECASTS
SEED EXCHANGE DEMONSTRATION FIELDS 60% IN STANDARD VARIETIES
DEMONSTRATIONS OF WHEAT OATS BARLEY, CORN and SORGHUM TILLAGE METHODS CROP ROTATION and SWEET CLOVER DEMONSTRATIONS
50% OF FARMERS UNDERSTANDING PRINCIPLES OF INSECT CONTROL
40% CONTROL OF WHEAT and SORGHUM SMUT DEMONSTRATIONS
SECOND PERIOD
COUNTY WIDE DEMONSTRATIONS WITH MILLS and ELEVATORS BUYING and SELLING ON QUALITY and GRADE BASIS
5% OF WHEAT GROWERS USING MARKET FORECASTS
SEED SUPPLY SEED EXCHANGE VARIETY and PURITY and GERMINATION DEMONSTRATIONS
MOISTURE CONSERVATION METHODS DEMONSTRATIONS OF FALLOW OR WIDE SPACING CORN and KAFIR COMPARISON, AND RATE OF SEEDING KAFIR WHEAT TILLAGE
ORGANIZED COMMUNITIES IN INSECT CONTROL DEMONSTRATION PLOTS CONTINUE LEADER TRAINING
WHEAT and SORGHUM SEED TREATMENT PLOTS DEMONSTRATIONS
FIRST PERIOD
LECTURES and DEMONSTRATIONS ON SELLING and BUYING ON QUALITY and GRADE BASIS
ANALYSIS OF MARKET SITUATION ISSUING OF MONTHLY MARKET TRENDS
SUPPLY PURE SEED SEED EXCHANGES VARIETY TESTS STANDARD VARIETIES and GERMINATION and PURITY TEST DEMONSTRATIONS
SUMMER FALLOW OR WIDE SPACING DEMONSTRATIONS WEED CONTROL MOISTURE SUPPLY WHEAT CORN and SORGHUM CULTURE
DEMONSTRATIONS OF INSECT CONTROL STUDY OF LIFE and HABITS OF HESSIAN FLY CUT WORM CHINCH BUG and GRASSHOPPERS LEADER TRAINING
SEED TREATMENT DEMONSTRATIONS IN FIVE TOWNSHIPS PER COUNTY
WHEAT MARKETING
CROP STANDARDIZATION
SOIL MANAGEMENT
INSECT CONTROL
SMUT CONTROL

FIG. 1.

The entomology, plant pathology, and marketing projects have shown like gains.—A. L. CLAPP, *Kansas State Agricultural College, Manhattan, Kans.*

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SODIUM NITRATE AS A FERTILIZER FOR WHEAT ON CERTAIN IOWA SOILS[1]

RAY A. PENDLETON[2]

Since wheat is one of our main food crops and an important crop in Iowa, it is quite desirable that attention should be directed to methods of producing a higher yield per acre and a better milling quality of grain. It would be very much worth while to find some fertilizer which would serve the double purpose of improving both the yield and quality of wheat. It appears from previous work that sodium nitrate might serve this double purpose under certain conditions.

For many years investigators have been studying the effects of nitrogen fertilizers on the yield and protein content of wheat. The literature along this line has been reviewed elsewhere and will not be discussed here. Suffice it to say, that earlier experiments show that different results may be expected from the use of sodium nitrate on different soils, under different climatic conditions, and in different seasons. There has been little work along this line on Iowa soils and this test was outlined with a view of obtaining some information regarding the desirability of using nitrates on wheat in Iowa.

EXPERIMENTAL

In the spring of 1928, two fields of winter wheat were selected for experimental work. One was on Shelby loam and the other on Waukesha silt loam. The results of the work on these two fields are given separately below.

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[1] Contribution from the Department of Soils, Iowa State College, Ames, Iowa. Received for publication January 25, 1930.

[2] Graduate Assistant. The author is indebted to the Chilean Nitrate of Soda Educational Bureau under whose auspices this work was made possible, to Dr. P. E. Brown for helpful suggestions and reading of the manuscript, and to Dr. F. B. Smith for his help in outlining the work.

FIELD I. SHELBY LOAM

The general plan of the experiment, which applies also for the other field, is given in Table 1.

TABLE 1.—*Treatments used in wheat fertilization.*

Plat No.	Treatment
1	Check
2	100 pounds sodium nitrate applied April 10
3	100 pounds sodium nitrate applied at heading time
4	200 pounds sodium nitrate applied April 10
5	200 pounds sodium nitrate applied at heading time
6	100 pounds sodium nitrate applied April 10 plus 100 pounds at heading time
7	50 pounds sodium nitrate applied April 10 plus 50 pounds at heading time
8	100 pounds sodium nitrate plus 120 pounds superphosphate applied April 10 plus 100 pounds sodium nitrate at heading time
9	Check

On the Shelby loam field all plats were 1/20 acre in size. The second application of fertilizer was made June 6, at which time the grain was just headed. At the time of the first treatment the soil showed a nitrate content of 16.9 p.p.m. and a pH of 5.36.

The results of the experiment on the Shelby loam are given in Table 2.

TABLE 2.—*Results of fertilizing wheat with sodium nitrate on Shelby loam.*

Plat No.	Yield in bushels per acre	Weight in pounds per bushel	Nitrogen in grain %
1	21.66	62.0	1.68
2	21.78	63.0	1.88
3	24.03	—	1.85
4	25.41	63.0	2.05
5	16.98	—	1.95
6	23.07	—	1.82
7	19.87	—	1.76
8	19.96	64.5	1.93
9	16.98	62.0	1.88

The yields are somewhat erratic in some instances and it is probable that other soil or seasonal factors may have caused the inconsistent results. The average yield from the two check plats was 19.32 bushels per acre. The average yield of all treated plats was 21.6 bushels per acre. This is only a small increase over the checks. The average yield from the plats receiving an early application of nitrate was 22.1 bushels per acre, or about 15% more than the yield on the checks. These increases, although small, are quite significant and worthy of further consideration.

The average nitrogen content of the grain from the check plats was 1.78%. The average nitrogen content of the grain from all treated plats was 1.88%. The average nitrogen content of the grain from the plats receiving a late application of nitrate was 1.86%

These data show an appreciable increase in protein content of the grain due to nitrate fertilization. The heavier applications of fertilizer were more effective in increasing the protein content than the lighter applications. The average nitrogen content of the grain from the plats receiving a total of 100 pounds per acre of sodium nitrate was 1.83%, and 1.93% from the plats receiving a total of 200 pounds per acre.

FIELD II. WAUKESHA SILT LOAM

The plan of the experiment for this field was essentially the same as for Field 1 except that 1/10 acre plats were used. The results are given in Table 3.

TABLE 3.—*Results of fertilizing wheat with sodium nitrate on Waukesha silt loam.*

Plat No.	Yield in bushels per acre	Weight in pounds per bushel	Nitrogen in grain %
1	19.05	60.0	1.73
2	21.78	61.0	1.72
3	22.68	61.0	1.92
4	29.04	60.0	1.81
5	lost	—	—
6	23.59	61.0	1.98
7	24.50	61.0	2.00
8	27.22	61.0	1.85
9	19.05	61.0	1.85

These data are somewhat more regular than those secured on the Shelby loam. The average yield from the check plats was 19.05 bushels per acre and the average yield from all fertilized plats was 24.80 bushels per acre, an increase of 32%. The average yield from the plats receiving only 100 pounds per acre of nitrate was 22.98 bushels per acre, an increase of 26% over that on the checks. The average yield from the plats receiving 200 pounds per acre of nitrate was 26.62 bushels per acre, an increase of 39.7% over that on the checks. This increase is very significant and indicates possibilities of profitable results from the use of sodium nitrate as a fertilizer for wheat on this soil type.

The average nitrogen content of the grain from the check plats was 1.79% and the average nitrogen content of the grain from all treated plats was 1.88%. On this field the early application of the fertilizer did not increase the nitrogen content of the grain over that on the check plats, but the nitrogen content of the grain receiving a late application of fertilizer was 1.94%, representing an increase of 8.4% over that on the check plats.

These data indicate that the later applications of sodium nitrate to wheat tend mainly to produce an increase in the protein content of the grain and the early applications tend to produce an increase in yield.

CONCLUSIONS

The data given above show that on certain soil types in Iowa increases in the yield of wheat may be expected from top dressings with sodium nitrate.

From these limited data it is difficult to determine which treatment may be the more profitable. The later applications were somewhat more efficient in increasing the protein content of the grain and approximately equal in increasing the yield when compared to the early treatments. However, there is more difficulty connected with applying fertilizer to wheat at the later stages of growth.

A top dressing of 100 or 200 pounds per acre of sodium nitrate to winter wheat in the early spring can be easily applied and might be very profitable.

The increase in the weight per bushel due to the fertilizer treatment was not sufficient to be significant on either soil type.

The increase in yield produced by the fertilizer was of more significance than the increase in protein content.

The returns secured from the use of superphosphate were not appreciable on either soil type.

RATE OF INTAKE, ACCUMULATION, AND TRANSFORMATION OF NITRATE NITROGEN BY SMALL GRAINS AND KENTUCKY BLUEGRASS[1]

M. M. McCool and R. L. Cook[2]

In previous papers[3] the authors have reported some of the results of their studies on the composition of the expressed sap of various crops. The effect of soil type, fertilizer applications, and stage of growth on the concentration of phosphorus and nitrate nitrogen has been shown.

It seemed advisable also to study the intake, the accumulation, and the rate of transformation of nitrate nitrogen by wheat, barley, oats, and Kentucky bluegrass. The results of experiments on the composition of the juice as affected by equivalent amounts of ammonium sulfate, urea, nitrate of soda, and ammonium phosphate at different intervals of time after their application to the soil are reported and discussed briefly in this paper. Data which show the rate of transformation of nitrate nitrogen in the sap, and also the effect of the amount of nitrate nitrogen in the medium in which plants are grown on the nitrate and phosphorus content of the expressed juice, are included. A review of the literature is given in the first publication referred to above.

PROCEDURE

Barley was planted in flats on Hillsdale sandy loam. Seventeen days later, when the plants had attained a height of about 6 inches, they were treated with equivalent amounts of ammonium sulfate, urea, and sodium nitrate. These carriers were applied in solution to the soil without touching the leaves of the plants. Twelve hours later and at frequent intervals during the following four weeks the plants were sampled, the moisture content determined, and the expressed saps analyzed for nitrate nitrogen. At the last sampling nitrate determinations were made on the soil in each flat.

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[1] Contribution from the Soils Department, Michigan State College, East Lansing, Mich. Published with the approval of the Director of the Michigan Agricultural Experiment Station as Journal Article No. 35 (N. S.). Received for publication March 13, 1930.

[2] Head of Department and Research Assistant in Soils, respectively.

[3] Cook, R. L. The effect of soil type and fertilizer on the nitrate content of the expressed sap and the total nitrogen content of the tissue of the small grains. Jour. Amer. Soc. Agron., 22:393–408. 1930.

McCool, M. M., and Weldon, M. D.—The effect of soil type and fertilization on the composition of the expressed sap of plants. Jour. Amer. Soc. Agron., 20:778–792. 1928.

A more extensive series similar to the above was set up in which oats instead of barley were grown. In this series the plants were 42 days old before they were treated with varying amounts of the three nitrogen carriers. Analytical determinations were made on the plant sap and soil corresponding to those in the first series.

Later on it was decided to experiment similarly with ammonium phosphate. Accordingly, several flats of Hillsdale sandy loam were prepared and planted to barley. Seventeen days later one-third of the flats were treated with sodium nitrate at the rate of 200 pounds per acre and one-third with an equivalent amount of ammonium phosphate. The check and sodium nitrate flats received sufficient amounts of calcium phosphate to make the phosphorus application equal on all the flats. The analytical determinations were made as described above.

Similar studies were made under field conditions. On November 6, 200 pounds each of ammonium sulfate and urea were applied as a top dressing on wheat plants which were about 6 inches in height. Nitrate determinations were made on the expressed sap of these plants after 9 and 24 days, respectively Kentucky bluegrass was also treated with sodium nitrate and urea each at the rate of 200 pounds per acre. The expressed sap was tested for nitrate 9 days after treatment.

About this time the question regarding the rate of transformation of nitrate nitrogen in the plants arose. Accordingly, oats and barley were grown in water cultures. Glass bowls of 600-cc capacity were used as containers in one series and 2-gallon jars in the others. The seeds were sprouted and placed on paraffined paper with the roots extending into the culture solution As soon as the plants had attained sufficient growth to furnish a sample sufficiently large for analyses, the nutrient solution was changed in one-half of the cultures. Instead of a full nutrient solution one-half of the containers were filled with a solution which lacked nitrogen. Precautions were taken to avoid contaminating the leaves of the plants with the nutrient solution in order that the results obtained might be the actual concentrations of nitrate in the expressed sap of the plants.

In order to determine the effect of the amount of nitrate nitrogen in the medium on the nitrate and phosphorus content of the expressed sap of the plants, wheat was grown in sand cultures. A complete nutrient solution was used in all cases, the only difference being the amount of nitrate nitrogen in the solution. The wheat plants were germinated in quartz sand, then transplanted to cultures of quartz sand. Tiles 4 inches in diameter and 12 inches high were employed as containers. The nutrient solution was siphoned onto the sand sufficiently rapid to result in its percolation through it at a slow but continuous rate. This was done in order to maintain a fairly uniform solution. When the plants had attained sufficient growth they were cut, weighed, and the expressed sap tested for nitrate nitrogen and phosphorus.

A detailed description of analytical methods has been reported by Cook in the paper mentioned above.

EXPERIMENTAL RESULTS

When some form of soluble nitrogen is placed in contact with the roots of a plant the intake and accumulation of nitrate by the plant may be quite rapid. The results presented in Table 1 show that after such treatment the concentration of nitrate in the expressed sap of barley rapidly increased. Ammonium sulfate and urea were slower in their effect than was sodium nitrate, due to the time element involved in the transformation of their nitrogen to the nitrate form. At the end of 36 hours the plants treated with sodium nitrate showed a considerable increase in the nitrate content of the sap. Six days after treatment these plants contained almost three times as much nitrate as did those which were not treated with nitrogen, whereas the plants grown in the containers which had received urea and ammonium sulfate contained, respectively, only about 2 and 1½ times as much.

TABLE 1.—*The effect of different nitrogen carriers on the rate of intake and accumulation of nitrate nitrogen in barley, greenhouse studies.*

	Nitrate nitrogen in p.p.m. at various periods after treatment							
Treatment	12 hours	36 hours	60 hours	84 hours	6 days	8 days	14 days	28 days
Check	1,080	928	744	765	793	831	910	603
Ammonium sulfate	1,070	872	928	1,070	1,259	1,456	1,330	828
Urea	1,115	1,080	950	1,184	1,542	1,500	1,632	1,040
Sodium nitrate	1,045	1,182	1,267	1,360	1,945	1,595	1,673	1,126

At the time of the last sampling the soil in each flat was sampled and the nitrate content determined. As shown by Table 2, there is a correlation between the concentration of the nitrate nitrogen in the soil and in the sap of the plants grown on it.

TABLE 2.—*A comparison of the nitrate nitrogen content of the expressed sap of barley plants and the soil.*

	Nitrate nitrogen in p.p.m. 28 days after treatment		Ratio treated flat to check, 28 days after treatment	
Treatment	Sap	Soil	Sap	Soil
Check	603	50	1	1
Ammonium sulfate	828	82	1.37	1.64
Urea	1,040	100	1.72	2.00
Sodium nitrate	1,126	143	1.87	2.86

TABLE 3.—*A comparison of the effect of nitrogen carriers on the moisture content of barley.*

Treatment	Grams of H_2O per gram of dry weight at various periods after treatment: 12 hours	36 hours	60 hours	84 hours	6 days	8 days	14 days	28 days
Check	7.28	6.82	6.65	7.00	6.07	5.61	5.65	4.66
Ammonium sulfate	7.78	6.96	7.08	6.79	6.13	6.25	5.12	4.98
Urea	7.51	7.18	7.10	7.20	6.27	5.82	5.46	5.84
Sodium nitrate	7.42	7.11	7.08	6.84	5.97	6.48	5.15	5.72

An examination of the data in Table 3 shows that in most cases the moisture content of treated plants was higher than that of untreated plants. This was true in the case of the ammonium sulfate and urea treatments during the first 36 hours, while the results in Table 1 seem to show a decrease in nitrate content during that period. The same thing is also shown in Tables 4 and 6. This behavior seems to indicate that the plants may have taken up nitrogen in some form other than as nitrate nitrogen.

TABLE 4.—*The effect of varying amounts of nitrogen fertilizer on the rate of intake and accumulation of nitrogen in oats, greenhouse studies.*

Treatment*	Nitrate nitrogen in p.p.m. at various periods after treatment: 15 hours	39 hours	63 hours	135 hours	13 da
Check	107	96	90	92	27
Ammonium sulfate	61	91	120	78	36
Ammonium sulfate	68	97	120	143	59
Ammonium sulfate	92	163	208	202	394
Urea	104	159	120	166	32
Urea	85	138	144	346	185
Urea	85	119	114	208	500
Sodium nitrate, 60	119	266	287	224	100
Sodium nitrate, 120	185	480	518	404	300
Sodium nitrate, 240	155	493	528	558	1,182

*The sodium nitrate applied at the rate of 60, 120, and 240 pounds, respectively, with the other carriers in equivalent amounts.

The results presented in Table 4 show that oats are similar to barley in their response to the application of nitrogen fertilizers. Ammonium sulfate and urea seemed to cause a decrease in nitrate nitrogen during the first 15 to 36 hours, and then a steady increase up to 135 hours. Sodium nitrate caused an increase in the nitrate content of the sap in 15 hours and it continued to increase steadily until the last period of sampling. After 13 days there was a decrease in nitrate in all the plants receiving the smaller applications of nitrogen, due, no doubt, to the inadequate supply in the soil.

During this series the soil was tested two different times and Table 5 shows that there is a rather close correlation between the nitrate content of the soil and that of the expressed sap of the plants. An

TABLE 5.—*A comparison of the nitrate nitrogen content of oat plants and the soil.*

	135 hours after treatment				13 days after treatment			
	Nitrate nitrogen in p.p.m.		Ratio treated flat to check		Nitrate nitrogen in p.p.m.		Ratio treated flat to check	
Treatment*	Sap	Soil	Sap	Soil	Sap	Soil	Sap	Soil
Check	92	2.8	1.00	1.00	27	1.7	1.00	1.00
Ammonium sulfate	78	2.5	0.85	.89	36	2.0	1.33	1.18
Ammonium sulfate	143	2.8	1.55	1.00	59	2.0	2.18	1.18
Ammonium sulfate	202	8.8	2.20	3.14	394	6.4	15.15	3.76
Urea	166	3.2	1.80	1.14	32	1.6	1.18	0.94
Urea	346	7.4	3.82	2.64	185	2.9	6.85	1.74
Urea	208	13.1	2.26	4.68	500	26.3	18.51	15.45
Sodium nitrate, 60	224	4.6	2.43	1.64	100	2.5	3.70	1.47
Sodium nitrate, 120	404	8.6	4.40	3.07	300	2.4	11.11	1.41
Sodium nitrate, 240	558	95.0	6.07	33.90	1,182	57.2	43.80	33.63

*Sodium nitrate applied at rates of 60, 120, and 240 pounds, respectively, with the other carriers in equivalent amounts.

increase in soil nitrate is usually accompanied by an increase in the nitrate content of the expressed sap of the crop.

TABLE 6.—*The effect of nitrogen fertilizers on the moisture content of oat plants, greenhouse studies.*

	Grams of H_2O per gram dry weight at various periods after treatment				
Treatment*	15 hours	39 hours	63 hours	135 hours	13 days
Check	7.65	7.65	7.34	6.67	6.62
Ammonium sulfate	7.86	8.65	6.81	6.99	6.16
Urea	8.68	9.00	8.19	8.12	9.06
Sodium nitrate, 240	7.60	5.95	6.66	6.99	7.20

*Sodium nitrate applied at the rate of 240 pounds, with the other carriers in equivalent amounts.

TABLE 7.—*A comparison of the effect of ammonium phosphate and sodium nitrate on the rate of intake and accumulation of nitrate nitrogen in barley.*

	Nitrate nitrogen in p.p.m. at various periods after treatment			
Treatment	16 hours	40 hours	64 hours	112 hours
Check	237	118	58	36
Ammonium phosphate	155	105	116	91
Sodium nitrate	383	743	754	684

TABLE 8.—*A comparison of the effect of equivalent amounts of ammonium phosphate and sodium nitrate on the moisture content of barley plants.*

	Grams of H_2O per gram dry weight at various periods after treatment			
Treatment	16 hours	40 hours	64 hours	112 hours
Check	6.49	6.67	7.15	7.57
Ammonium phosphate	7.28	7.22	8.83	8.35
Sodium nitrate	11.45	14.30	12.25	8.06

The results presented in Tables 7 and 8 show that ammonium phosphate acts similarly to ammonium sulfate in its effect on the intake and accumulation of nitrate nitrogen. Immediately after treatment it seems to cause a decrease of the nitrate in the sap and later a gradual increase, indicating again the possibility that the plants may have taken up nitrogen in some other form. It does not seem likely that the decrease is due to a depression of nitrification in the soil because the plants increased in moisture content, a condition which usually accompanies the intake of nitrogen.

TABLE 9.—*The effect of different nitrogen carriers on the rate of intake and accumulation of nitrate nitrogen in wheat plants, field studies.*

Treatment	Nitrate nitrogen in p.p.m. 9 days	24 days
Check	80	75
Urea	90	74
Ammonium sulfate	112	75
Sodium nitrate	121	84

Under field conditions the rate of intake and accumulation of nitrate by wheat plants, as shown in Table 9, were considerably slower than in the case of barley in the greenhouse. This may be accounted for by the fact that the fertilizer was applied broadcast in crystalline form rather than in solution. Here again the plants treated with urea are lower in nitrate content than those treated with sodium nitrate, but in moisture content, as indicated by the results given in Table 10, they are about the same.

TABLE 10.—*A comparison of the effect of nitrogen carriers on the moisture content of wheat plants.*

Treatment	Grams of H_2O per gram dry weight 9 days	24 days
Check	3.17	2.97
Urea	3.28	2.90
Ammonium sulfate	—	2.84
Sodium nitrate	3.25	3.03

Bluegrass was treated with nitrogen in solution and the data in Table 11 show that the results were similar and just as striking as were those obtained with oats and barley in the greenhouse.

TABLE 11.—*The effect of nitrogen carriers on the nitrate content of the expressed sap of bluegrass, field studies.*

Treatment	Nitrate nitrogen in p.p.m. after 9 days
Check	97
Urea	115
Sodium nitrate	254

The data presented in Tables 12 and 14 show the results of our endeavor to ascertain the rate of transformation of nitrate nitrogen in the plants. According to Table 12, the nitrate had to be removed from the nutrient solution for only 7½ hours to cause a decrease from over 200 to about 40 p.p.m. The results shown in Table 13 are similar to those in Table 12 except that the differences are not so great. This may be due to the fact that the last series was grown during the hot summer weather and as a result the plants were not

TABLE 12.—*The rate of transformation of nitrate nitrogen in the expressed sap of oats plants, water cultures.*

	Nitrate nitrogen in p.p.m. at various periods after treatment	
Treatment	7.5 hours	24 hours
NO_3 removed	44.0	20.0
NO_3 removed	36.0	29.0
NO_3 not removed	252.0	58.0
NO_3 not removed	196 0	65.0

TABLE 13.—*The rate of transformation of nitrate nitrogen in the expressed sap of barley plants, water cultures.*

	Nitrate nitrogen in p.p.m. at various periods after treatment				
Treatment	1 hour	3 hours	6 hours	21 hours	61 hours
NO_3 removed	1,836	940	1,003	838	1,107
NO_3 not removed	1,362	1,735	1,268	1,295	1,721

growing as fast as they were in the first series which was grown in the early spring.

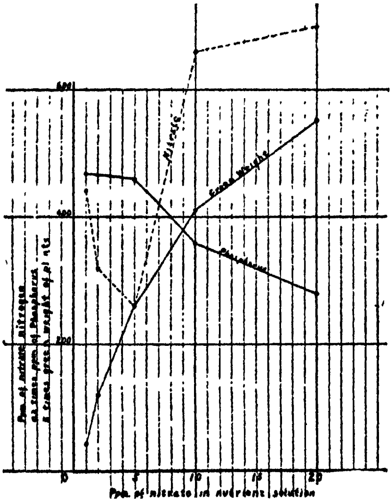

FIG. 1.—The effect of varying amounts of nitrate nitrogen in the medium on the nitrate and phosphorus content of the expressed sap of wheat plants.

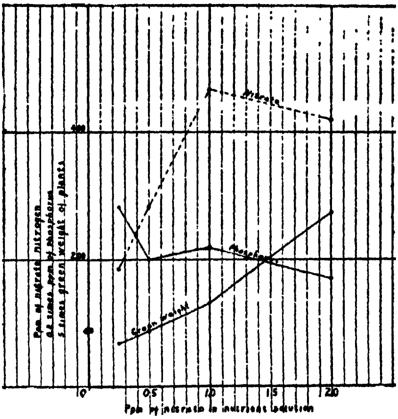

FIG. 2.—The effect of varying amounts of nitrate nitrogen in the medium on then itrate and phosphorus content of the expressed sap of wheat plants.

TABLE 14.—*The effect of the transformation of nitrate nitrogen on the moisture content of the barley plant, water cultures.*

	Grams of H_2O per gram dry weight at various periods after nitrate was removed				
Treatment	1 hour	3 hours	6 hours	21 hours	61 hours
NO_3 removed	11.9	10.6	9.0	9.1	7.1
NO_3 not removed	10.7	9.9	10.3	10.3	10.2

A consideration of the data presented in Table 14 shows again the effect of nitrogen on the moisture content of plants. Shortly after the nitrate was removed from the nutrient solution the moisture content of the plants began to decrease steadily, while the plants with nitrate contained about the same amount of moisture throughout the experiment.

The graphs presented in Figs. 1 and 2 represent the results obtained by growing wheat plants on a medium containing varying amounts of nitrate nitrogen. By examining the graphs it is apparent that the green weight of the plants increased steadily right up to the highest concentration of nitrate in the nutrient solution. A comparison of the nitrate and phosphorus curves shows that in general phosphorus decreases and nitrate increases as the green weight of the plants becomes larger. Both graphs show a decrease of nitrate in the expressed sap between concentrations of 1 and 2 p.p.m. of nitrate in the nutrient solution. In the series represented by Fig. 1 there were no cultures containing less than 1 p.p.m. nitrate nitrogen. If there had been, perhaps the nitrate curve would have gone up between ¼ and 1 p.p.m. as it did in the second series. A decrease in the phosphorus content of the sap accompanying increased growth, due to the addition of some other element as a fertilizer, is in keeping with the results obtained by McCool and Weldon cited above.

CONCLUSIONS

It appears logical to draw the following conclusions from these studies:

1. The intake by plants of nitrogen added to the soil is very rapid, showing up in the expressed sap in 15 hours after treatment.
2. Changes in the concentration of nitrate nitrogen in the soil are usually accompanied by proportional changes in the expressed sap of the crop.
3. Sodium nitrate causes a quicker and greater increase in the nitrate content of the expressed sap than do either ammonium sulfate, urea, or ammonium phosphate.
4. The rate of transformation of nitrate nitrogen in the plant is very rapid, as indicated by a considerable decrease in the nitrate content of the expressed sap of plants three hours after the source of nitrate supply was removed.
5. Wheat plants grown in sand cultures did not attain maximum growth, although some of the cultures contained as much as 20 p.p.m. of nitrate.
6. In general, an increase of nitrate nitrogen in the sand cultures was accompanied by increased growth, an increase in the concentration of nitrate nitrogen, and a decrease in the concentration of phosphorus in the expressed sap of the plants.

EFFECT OF FERTILIZERS ON THE YIELD AND COMPOSITION OF WHEAT[1]

H. F. MURPHY[2]

There have been considerable data presented from time to time relative to the composition of the soil and its influence on plant composition. Fertilizers have been used for a long period of time to increase crop yields, and their influence on plant composition has also been an interesting and important problem. This latter performance, while it has been pointed out as a very important factor, has not as yet been fully studied. It will always remain a factor contributing to the quality of the product produced from the soil.

Quality (whatever this may be) of wheat has received considerable thought in the wheat belt and as yet remains unsolved. Common measures of quality have been test weight per bushel and protein content. Whatever these may contribute to the makeup of quality in wheat still remains undetermined, yet they are means of expressing something at least regarding the milling and baking value of the wheat kernel.

In 1924, there was started by the writer at the Oklahoma Experiment Station a fertilizer experiment based on the triangular system in which the quality as well as the yield of wheat was to be studied. Yields of grain and straw, protein analyses, and milling and baking studies have been made during this time. It is the purpose of this paper to present the protein and phosphorus studies for the last two years along with the yield of grain secured.

While the original fertilizer plan has been greatly enlarged, only those treatments included in the triangular system are given and discussed.

The fertilizers used were superphosphate (16% P_2O_5), nitrate of soda, and kainit. The total application was 300 pounds of fertilizer per acre. The fertilizers have been applied in the fall just following the seeding of the wheat by broadcasting them over the surface. The plats used are 1/20 acre and are located on what would be considered a good grade of Kirkland sandy loam soil for this section. This soil is characterized by its brownish color in surface and subsoil, its rather impervious subsoil, its nearly level topography, and its relative inability to allow root extension and moisture penetration. Thus, during dry seasons, crops grown on this soil suffer considerably for

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[1] Contribution from the Department of Field Crops and Soils, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Received for publication March 20, 1930.

[2] Associate Professor of Soils.

lack of moisture. Small grains, however, do fairly well when the soil is fairly well supplied with organic matter and plant food because climatic conditions in this section are generally favorable during the growing period of this type of crop.

The plan of the experiment is shown in Fig. 1 and the plat treatments are given below:

Plat No.*	Annual treatment per acre
1	Unfertilized
2	300 pounds superphosphate
3	225 pounds superphosphate, 75 pounds kainit
4	225 pounds superphosphate, 75 pounds nitrate of soda
5	Unfertilized
6	150 pounds superphosphate, 150 pounds kainit
7	150 pounds superphosphate, 75 pounds nitrate of soda, 75 pounds kainit
8	150 pounds superphosphate, 150 pounds nitrate of soda
9	75 pounds superphosphate, 225 pounds kainit
10	Unfertilized
11	75 pounds superphosphate, 75 pounds nitrate of soda, 150 pounds kainit
12	75 pounds superphosphate, 150 pounds nitrate of soda, 75 pounds kainit
15	Unfertilized
16	300 pounds kainit
17	75 pounds nitrate of soda, 225 pounds kainit
18	150 pounds nitrate of soda, 150 pounds kainit
19	Unfertilized
20	225 pounds nitrate of soda, 75 pounds kainit
21	300 pounds nitrate of soda
23	Unfertilized
27	75 pounds superphosphate, 225 pounds nitrate of soda

*The missing plats are fertilized with other materials not included in the triangular system.

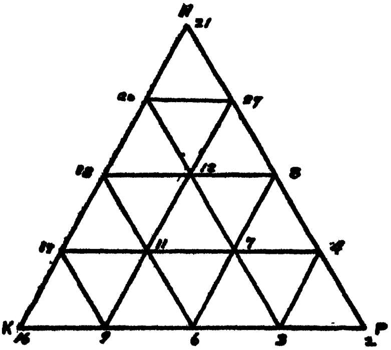

FIG. 1.—Showing plat numbers and ratio treatments.

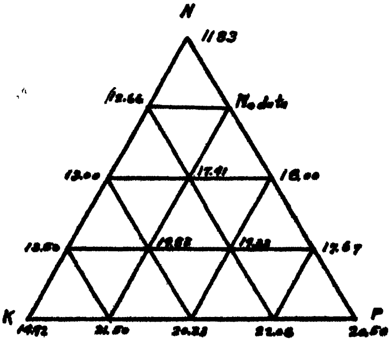

FIG. 2.—Showing the average yield of wheat per acre for 1928 and 1929. Yield of unfertilized wheat = 14 bushels per acre.

In Fig. 2, the yields of wheat are given for the various treatments. It can be readily seen that neither nitrogen nor potash nor their combinations will increase the yield of wheat on these soils. These fertilizers used singly or together in the various combinations have yielded less than unfertilized plats along side of them. As soon as phosphorus is introduced into the fertilizer, the yield begins to pick up. Phosphorus and potash combinations have given larger yields than phosphorus and nitrogen or a combination of all three elements. The highest yielding combination has been 225 pounds of superphosphate and 75 pounds of kainit. It is interesting to note that this is one of the first plats to mature in the whole series. It is also interesting to note that all plats receiving phosphorus tend to lodge worse than the others if adverse conditions prevail during the last stages of development. Plats 4 and 8 lodge somewhat worse than the others, while Plat 6 lodges least, as a general rule, of the phosphated plats. The phosphated plats always present a more thrifty condition during the growing season. Plats 3 and 9 ripen from a day or two to as much as a week earlier than the other plats. Plat 6 is a close second so far as date of ripening is concerned.

In Figs. 3, 4, 5, and 6, the protein content of the wheat is given. Among the interesting things shown in these figures are the following:

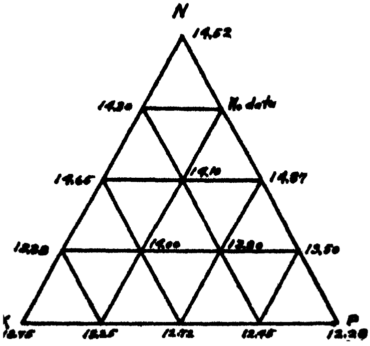

FIG. 3.—Showing the influence of fertilizers on the protein content of the 1928 wheat crop. (Protein expressed in %.) Protein content of wheat grown on unfertilized soil = 13.62%.

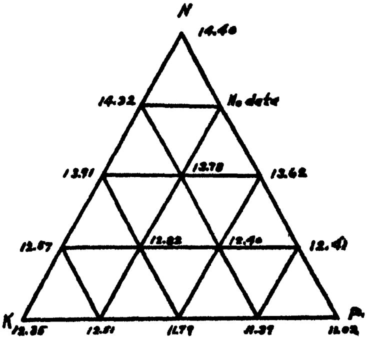

FIG. 4.—Showing the influence of fertilizers on the protein content of the 1929 wheat crop. (Protein expressed in %.) Protein content of wheat grown on unfertilized soil = 13.27%.

(1) The protein content rises as the amount of nitrogen in the fertilizer is increased. Seventy-five pounds of nitrate of soda did increase the protein content over untreated soils. The use of 150 pounds gave the greatest increase per unit of nitrogen supplied. Above 150 pounds of nitrate of soda, the increase in protein content was very slight, as a rule. (2) With the introduction of phosphorus in the fertilizer whether by itself, with nitrogen or with potash, the protein

content decreased. (3) Potash showed a reduced effect one year and practically no effect the other. (4) As an average for the two years, the potash treatment was a little below normal (normal being considered the protein content of wheat grown on unfertilized soil), the phosphorus treatment almost 2% below normal, and the nitrogen treatment about 1% above normal, there being a spread of almost 3% in protein content between the wheat produced on soil fertilized with superphosphate alone and that produced on soil fertilized with nitrate of soda alone.

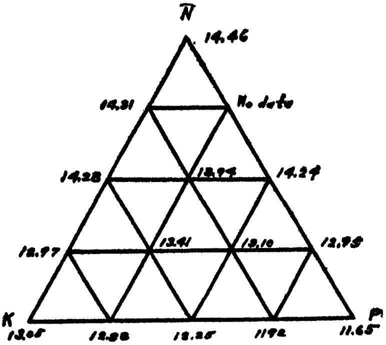

FIG. 5.—Showing the influence of fertilizers on the protein content of wheat. (Average for 1928 and 1929.) Protein content of wheat grown on unfertilized soil (average of 2 years) = 13.44%.

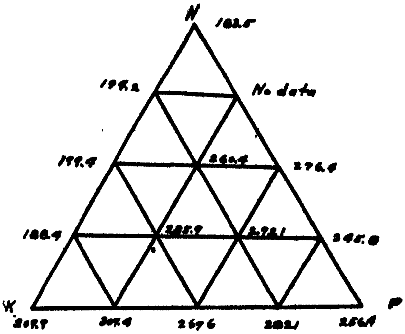

FIG. 6.—Showing the total acre yield o protein in pounds for 1928 and 1929 Protein yield on unfertilized soils = 19 pounds.

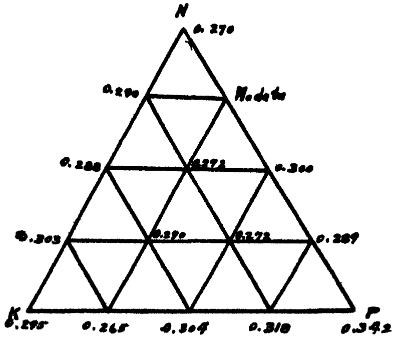

FIG. 7.—Showing the phosphorus content in % of fertilized wheat for 1928. Phosphorus content of unfertilized wheat = 0.282%.

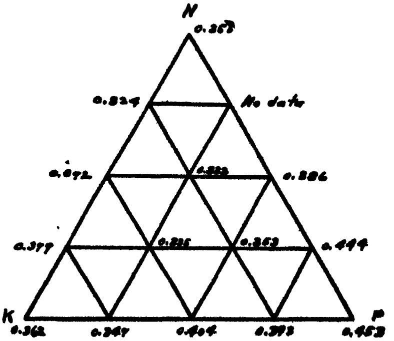

FIG. 8.—Showing the phosphorus content in % of fertilized wheat for 1929. Phosphorus content of unfertilized wheat = 0.359%.

Plat 9 (fertilized with a 3:1 ratio of kainit and superphosphate) ripens along with Plat 3. These two plats ripen earlier than any others. These two plats are the highest yielding plats so far as bushels per acre are concerned. Plat 9 is first when it comes to acre yield of protein with Plats 11 and 3 ranking second and third in this respect. Plat 9 yielded 21.5 pounds per acre more protein as a total for the years 1928 and 1929 than did Plat 11, and 25.3 pounds more than Plat 3. The phosphorus content of the grain produced on Plat 9 has been lower than any of the plats treated with the other potash-phosphorus ratios. It has been good in kernel plumpness.

Figs. 7, 8, and 9 present data showing the effect of fertilization on the phosphorus content of the grain. Among other things brought out by these figures are the following: (1) The plats receiving 300 pounds of superphosphate only per acre had the highest percentage of phosphorus in the grain. (2) Ratios of 3 parts of superphosphate to 1 part of nitrate of soda or 1 part of kainit, and 2 parts of superphosphate to 2 parts of nitrate of soda or 2 parts of kainit also yielded grain with higher phosphorus content than the other treatments or the unfertilized soil. (3) Where all three elements were furnished as indicated by the figures in the central portion of the charts, the percentage of phosphorus in the grain is below that in the grain produced on unfertilized soil. (4) The phosphorus content of the grain was higher where potash alone was supplied than where nitrogen alone was supplied. (5) A high amount of kainit with a small amount of nitrate of soda (ratio 3:1) produced a wheat whose phosphorus content was higher than where either potash or nitrogen alone was supplied. (6) A small amount of superphosphate with a large amount of kainit (ratio 1:3) showed a depressing effect on the phosphorus content.

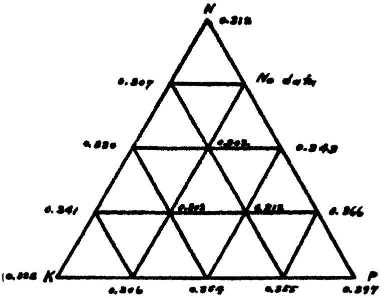

FIG. 9.—Showing the average phosphorus content in % of fertilized wheat for 1928 and 1929. Phosphorus content of unfertilized wheat (2-year average) =0.320%.

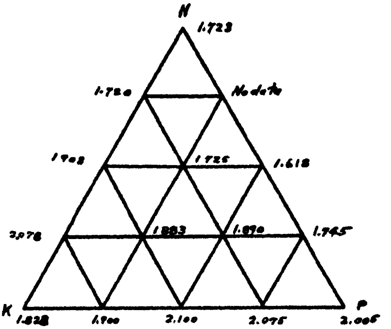

FIG. 10.—Showing the weight in grams of 100 kernels of variously fertilized wheat. Weight of 100 kernels of unfertilized wheat = 1.733 grams.

Fig. 10 gives some interesting information relative to the plumpness of the grain produced. The plumpest kernels were produced on soil fertilized with kainit and superphosphate in the ratio 1:1. Higher ratios of superphosphate to kainit likewise produced very plump kernels. With kainit alone or with nitrogen alone the kernels had less plumpness. Where nitrogen in large amounts was used the kernels shrivelled considerably and were less plump than where no fertilizers were used. The protein content (as was observed in Figs. 3, 4, and 5) was higher with these treatments, however. The 1:1 ratio of kainit and superphosphate has produced an excellent kernel, being both plump and of good texture. Its test weight per bushel has been close to the top each year. Total ash data for the 1929 crop is presented in Fig. 11.

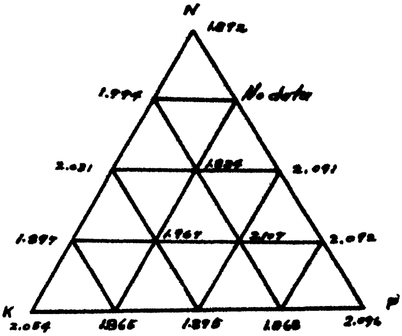

FIG. 11.—Showing the % of total ash present in wheat grain grown on fertilized soil. The total ash of wheat grown on unfertilized soil = 1.900%.

PREPARATION OF SOIL SAMPLES FOR PIPETTE ANALYSIS[1]

ERIC WINTERS, JR., AND M. B. HARLAND[2]

The pipette method, developed independently by Robinson in England, Krauss in Germany, and Jennings, Thomas, and Gardner in America, has gained widespread approval as a rapid means of determining the finer fractions in mechanical analysis. This method requires that the soil suspension be completely dispersed before sedimentation begins, whereas in decantation methods dispersion may be continued throughout the analysis by repeated puddling or rubbing. The diversity of opinion regarding the adequacy of deflocculating procedures and the probability that a given procedure is not equally effective on all soils led to the studies reported in this paper.

The problem of dispersion divides itself into three more or less definite sections, *viz.*, (a) kind and concentration of electrolyte; (b) the mechanical aspect of dispersion, i.e., time of shaking; and (c) pretreatment of the sample. The discussion of results in this paper will be presented in the above order.

The soils used in this work were obtained in Illinois. They represent fairly well the predominant types of the region, so that the results should be generally applicable in further laboratory studies of Illinois soils. Descriptions of the soils will be limited to the series name and the horizon designation. The horizons are designated by the letters, A, B, C, D, and E, as proposed by Smith and Norton (9).[3]

METHOD

Each sample, consisting of the approximate equivalent of 10 grams of oven-dry soil, was shaken in a rubber-stoppered, 2-quart bottle with about 750 cc of water and electrolyte in an end-over-end machine averaging about 55 R. P. M. After shaking, the suspension was transferred to a rubber-stoppered glass cylinder with a diameter of about 60 mm, and made up to exactly 1,000 cc.

The cylinder containing the suspension was then placed in a water bath held at a temperature of 25.25° ± .05° C. This temperature approximated that of the laboratory, so that the tempering of the suspension in the bath required a minimum of time. When the sus-

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[2] Assistant and Associate in Soil Physics, respectively.

[3] Reference by number is to "Literature Cited," p. 779.

pension had attained the required temperature, the cylinder was removed, shaken end-over-end by hand, replaced in the bath, and sampled at the calculated time-depth interval by means of a pipette having four lateral openings. Suction for sampling was provided by a filter pump with a relief valve in the suction flask. With carefully adjusted screw clamps on the rubber tubing leading to the pipette, this device gave fairly uniform suction with a minimized surge into the pipette at the outset. A 25-cc aliquot was drawn in approximately 1 minute. The aliquot was placed in a weighing bottle with a ground glass cover, evaporated, and dried at 105° C, cooled, and weighed. After correcting for the amount of electrolyte present, the percentage of suspended material was calculated on the basis of oven-dry soil. All figures given are averages of duplicate determinations.

The time-depth ratios for the different fractions were calculated from Stokes' formula, using the following values: Density of water, 1.00; viscosity of water at 25.25° C, 8.88 x 10^{-3}; specific gravity of the soil 2.65. These values give the following relationships:

Equivalent diameter	Depth in cm	Time in hours
5μ	9.10	1.0
2μ	8.75	6.0
1μ	8.75	24.0

The above ratios will be found to be graphical equivalents of the international standard of 10 cm fall in 8 hours for 2μ if the nomograph "B" of Crowther (4) is used. It was often convenient to change the given times of sampling, especially for the longer periods. The experience of several workers has indicated that this may be done safely by making an appropriate depth correction, and such changes were frequently made.

THE DISPERSING AGENT

The choice of electrolyte used in deflocculation has been studied by numerous workers. Their findings have limited selection to a few materials. Therefore, only the two following compounds were given attention in the studies reported in this paper: First, sodium carbonate, because of the recognized effects of the Na ion on colloidal complexes; and second, ammonia, because it is still employed by many soil workers. Samples of untreated air-dry soil were shaken for an arbitrary period of 24 hours with varying concentrations of electrolyte and the amount of material with an equivalent diameter of less than 1 μ was determined as a criterion of the degree of dispersion. The soils used, with the one exception noted below, are given in Table 2.

The data for Na_2CO_3 (Fig. 1) show the same general relationships found by Puri and Keen (7), namely, that increased concentrations of Na_2CO_3 produce greater dispersion up to a given point, then fail to alter it appreciably over a certain range, and finally cause a decreased dispersion. Surface horizons exhibit a wider range of "tolerance" than do substrata, probably owing to the stabilizing influence of their organic-matter content. The extreme sensitivity of sample No. 117 seems related to properties which it possesses because of its position in the profile. It represents a transition zone between the carbonate-free B and the calcareous D horizons. Its properties are shared by other C horizons which have been studied. For D horizons, the electrolyte curve ceases to show such a sharp break and assumes a more normal form (Clarence D_2, No. 122, Fig. 1). It was subsequently learned that if C horizons are leached with N/10 HCl followed by thorough washing they lose their extreme "sensitivity" and can be handled as are other horizons, otherwise the electrolyte concentration for such horizons must be 0.09% Na_2CO_3 (15 cc of 4% Na_2CO_3 in 750 cc).

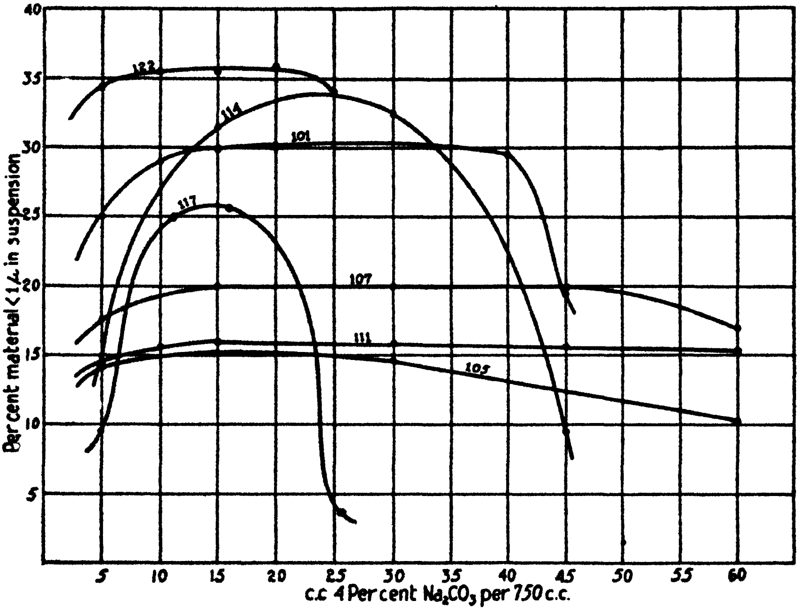

FIG. 1.—The effect of different concentrations of Na_2CO_3 on the degree of dispersion.

Excluding No. 117 (Clyde C) from consideration, a study of Fig. 1 reveals that at a concentration of 0.11% (20 cc of 4% Na_2CO_3 in

750 cc) all curves approach a maximum. This concentration is later reduced to 0.08% by dilution of the sample to 1,000 cc in the sedimentation cylinders. Puri and Keen found a higher optimum concentration, namely, 0.2%. Joseph and Snow (6) also use 0.2% during shaking, but subsequently dilute to 0.08% for sedimentation. Jennings, Thomas, and Gardner (5) suggest a tentative range of concentrations less than 0.05% for alkali soils. All of these concentrations may become satisfactory if the leaching with HCl is performed as suggested above.

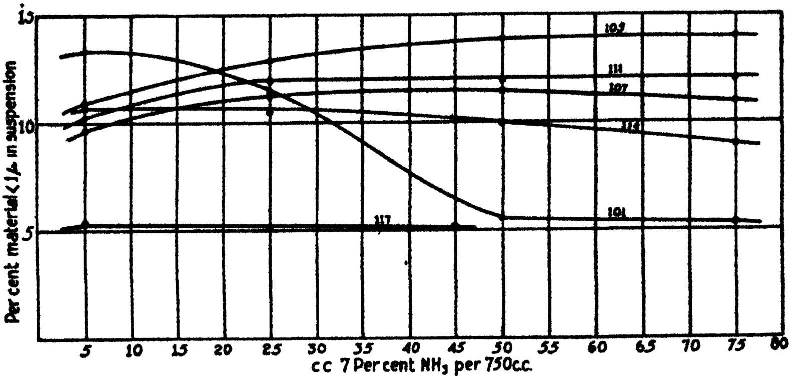

FIG. 2.—The effect of different concentrations of NH_3 on the degree of dispersion.

Changes in concentration of NH_3 (Fig 2) have little effect on dispersion except in the case of No 101 It is evident by comparing the curves in Fig 2 with those in Fig 1 that NH_3 is unsatisfactory for the pipette method where complete dispersion is desired with one operation.

TIME OF SHAKING

Using the optimum concentrations of Na_2CO_3 found above, the effect of varying periods in an end-over-end shaker on the degree of dispersion was studied Both moist and air-dry samples of untreated soils were used Here again the amount of material having an equivalent diameter of less than 1 μ was considered the measure of dispersion. The dispersion curves (Fig. 3) resemble those of Puri and Keen except that they become asymptotic in 48 hours, whereas those of Puri and Keen do not. Although the moist samples become asymptotic sooner than the air-dry ones, there appears to be no essential difference between the two conditions either in the general form of the curve or the position of the asymptote. This is contrary to the opinion of Puri and Keen, these differences probably arising from their using no deflocculant in that portion of their work.

In some later work in this laboratory, samples shaken in a reciprocating machine for 48 hours checked very well with those prepared in the end-over-end shaker. While shorter periods were not tried with the reciprocating shaker, it appears likely, because of its more vigorous action, that the dispersion curves might become asymptotic sooner than those in Fig. 3. This is true for the mixing machine of Bouyoucos (3), 10 minutes in it being the equivalent of 2 to 8 hours shaking (Fig. 3). Periods longer than 10 minutes were not investigated, because the mixer and suspension become heated, causing flocculation of some samples. Assuming the same form of curve as found with the shaker, it would require from 1 to 3 hours to approach the asymptote.

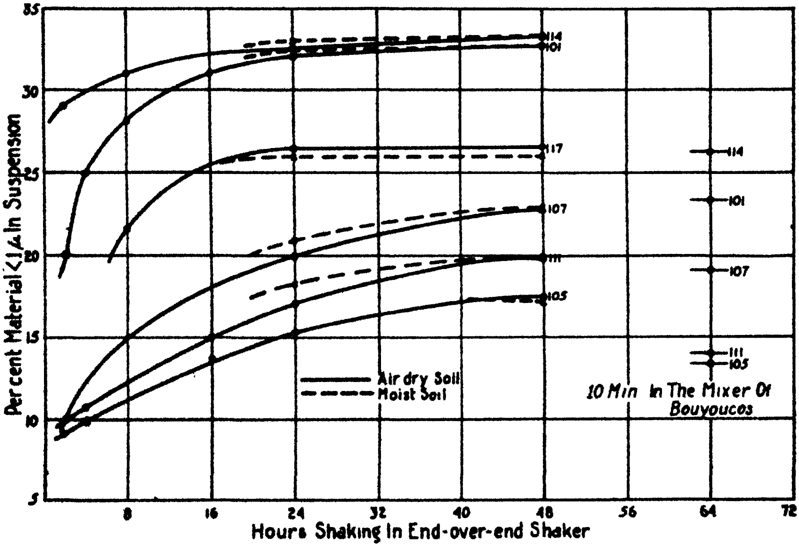

FIG. 3.—The effect of different periods of shaking on the degree of dispersion of moist and air-dry soils.

A period of 40 hours shaking is advised in the British official method (1): It is seen from Fig. 3 that such a time interval should be quite satisfactory. Joseph and Snow, however, suggest that 2 hours in a reciprocating machine is sufficient. Such may be the case if decantation and subsequent puddling is used or if the soil under consideration has a dispersion curve similar to No. 114. However, for a pipette analysis, the period should approach 48 hours for most of the samples reported in this paper.

The need for long-continued shaking may be related to an hydration process. Three soils, sampled after being shaken for 2 hours,

TABLE 1.—*The effect of hydration on the degree of dispersion.*

Sample No.	Series name	Horizon	Material $< 1\ \mu$ in suspension At first determination	After standing 24 hours
			%	%
105	Tama	A_1	8.7	10.0
111	Clyde	A_1	9.7	11.8
101	Putnam	B	20.2	23.2

were resuspended 24 hours after the first sampling and the material having an equivalent diameter of less than 1 μ was redetermined. The noticeable increase in dispersion (Table 1) is attributed to the hydration of aggregated colloidal particles, and subsequent dispersion of this hydrated material during resuspension. If this hypothesis is correct, the length of the shaking period is dependent on the rate of hydration and, for dispersion in a single operation, cannot be greatly shortened.

TABLE 2.—*The effect of storage of air-dry samples on the degree of dispersion.*

Sample No.	Series name	Horizon	Material $< 1\ \mu$ in suspension using Freshly air-dried soil	Air-dry soil stored 11 months
			%	%
105	Tama	A_1	17.5	15.4
107	Tama	A_3	23.0	20.0
111	Clyde	A_1	20.0	17.6
114	Clyde	B_1	33.0	31.0
117	Clyde	C	26.5	26.5
101	Putnam	B	33.0	29.0

Six of the air-dry samples previously used in this problem were stored during the summer and redetermined the following winter. In all but one instance, there resulted an appreciable reduction in dispersion (Table 2). This result likewise indicates that hydration, as suggested above, is a probable factor in dispersion, and that soils intended for mechanical analysis should either be kept in a moist condition or else analyzed promptly after collection.

PRETREATMENT OF SAMPLE

Three procedures commonly used in pretreatment are compared in this paper, *viz.*, (a) treatment with 15 to 25% H_2O_2, followed by N/10 HCl; (b) N/10 HCl alone; and (c) no treatment. All samples reported were subsequently shaken with 0.11% Na_2CO_3 for 48 hours. The summation percentages are given for the 5-μ and 2-μ in addition to the 1-μ fractions.

Several interesting relationships are found in the data. Comparing the H_2O_2-HCl treatment with no treatment, a fair agreement is found in the 5-μ fractions, but in most cases the former shows a higher percentage of material less than 1 μ in spite of the fact that the H_2O_2 has removed a portion of the organic colloids (differences must

TABLE 3.—*The effect of different pretreatment methods on the degree of dispersion.*

Sample No.	Series name	Horizon	Treatment	Material in suspension $< 5\ \mu$ %	$< 2\ \mu$ %	$< 1\ \mu$ %
417	Princeton	A_1	H_2O_2—HCl	16.2	12.5	10.1
			HCl	17.0	12.0	9.8
			None	16.8	11.7	9.0
429	Princeton	A_1	H_2O_2—HCl	20.5	12.8	9.0
			HCl	21.3	12.0	8.0
			None	20.4	10.6	6.7
539	Edina	A_1	H_2O_2—HCl	28.4	21.3	18.1
			HCl	31.6	22.2	17.1
			None	28.0	17.1	11.5
520	Slick Spot	A_1	H_2O_2 - HCl	19.7	15.7	15.1
			HCl	22.3	16.6	14.0
			None	21.0	16.0	13.0
402	Putnam	A_1	H_2O_2—HCl	18.2	13.1	11.8
			HCl	19.8	14.2	12.0
			None	19.3	12.3	8.6
430	Princeton	A_2	H_2O_2—HCl	22.6	13.9	10.8
			HCl	24.0	14.7	10.3
			None	23.0	13.6	10.0
420	Princeton	B_1	H_2O_2—HCl	33.0	27.2	25.7
			HCl	33.7	28.1	25.4
			None	32.9	26.4	21.9
541	Edina	B_1	H_2O_2—HCl	36.4	28.8	25.0
			HCl	38.4	29.8	25.0
			None	36.0	26.0	21.0
543	Edina	B_2	H_2O_2—HCl	50.1	43.3	38.8
			HCl	51.4	43.5	38.9
			None	51.0	40.6	33.8
551	Princeton	B_1	H_2O_2—HCl	30.3	25.4	22.6
			HCl	29.7	24.6	21.7
			None	29.3	22.7	18.5
521	Slick Spot	B_1	H_2O_2—HCl	46.5	41.1	40.2
			in HCl	51.6	45.8	40.6
			None	50.4	44.5	40.7
263	Clarence	D_2	HCl	47.0	34.0	27.2
			None	54.0	36.5	27.3
270	Clarence	D_2	HCl	55.1	41.9	33.8
			None	62.4	44.4	34.9
558	Princeton	D_1	HCl	10.7	8.5	6.8
			None	9.2	6.8	5.3

exceed 1 % to be significant). On the contrary, HCl alone checks fairly well with H_2O_2-HCl in the 1-μ fraction, but shows in several instances a considerable increase in 5-μ material. Lastly, the D horizon samples on which no H_2O_2 was used because of the presence of carbonates show the same percentage of 1-μ material whether the sample is leached with HCl or is untreated, while the 5-μ and 2-μ results are reduced by the acid treatment in Nos. 263 and 270 (Table 3).

An explanation of the above results seems to rest in part on the amount and condition of the organic fraction in the sample. The A horizons of the Princeton soils, which supported a timber growth, have a light-colored, somewhat fibrous organic content, in contrast to the darker, more thoroughly decomposed material in the Edina and Putnam soils, both of which were developed under a grass vegetation. The better humified material of the latter two acts as a more effective binder of the inorganic colloids, it can be dispersed to a greater extent by the Na ion after HCl treatment, and it appears to be attacked more readily by the H_2O_2. The Princeton A horizons, then, show no marked differences between treatments because of the non-colloidal properties of the organic matter, i.e., functionally it is absent.

The B horizons of all the soils studied contain less organic matter than the A horizons. As a result, there is better agreement between treatments in the amount of 5-μ material. There is also a more constant difference in 1-μ material after HCl pretreatment compared with no treatment. This indicates a fairly uniform degree of humification in all of the subsoils studied. Sample No. 521, does not contain enough organic matter to account for the 5% variation in 5-μ material, but the explanation may be found later in some of the unusual characteristics of slick spots.

Finally, in the D horizons, the organic-matter content is very low, and in its absence HCl pretreatment does not increase the amount of 1-μ material in suspension, presumably because there is no organic binder that needs removal or dispersion to permit the separation of the inorganic colloidal particles. However, HCl has reduced the amount of 5-μ material by 7% in Nos. 263 and 270, which loss must represent solution of carbonates (samples 558, 263, and 270 contain over 15% $CaCO_3$). The distribution of calcareous material in the range 1 μ to 5 μ in Nos. 263 and 270, and its apparent absence in No. 558, is of interest. It may be that a knowledge of the size distribution of carbonates is important, and will be required for a proper understanding of the physical behavior of calcareous horizons. Olmstead, *et al.* (8) have recently advanced this opinion as a result of their investigation of the effect of HCl pretreatment on the mechanical analysis of soils.

It appears that the advantage of H_2O_2 pretreatment arises chiefly from the subsequent washing with HCl, and that the H_2O_2 might therefore be omitted. A similar conclusion was reached by Joseph and Snow, who, however, would also eliminate acid pretreatment. Bodman (2) objects to the H_2O_2-HCl treatment because of the possibility of altering the colloidal fraction. This objection does not seem to hold with the soils used in the present study. There is a further objection to H_2O_2, namely, that only a part of the organic matter is decomposed, and this decomposed part is not allotted to any definite portion of the distribution curve. Pretreatment with HCl alone removes such ions as Ca and Mg, allowing ready dispersion of the organic material by Na_2CO_3, and thus destroys its binding effect on the inorganic colloids. The organic material then becomes a part of the suspension. The advisability of substituting sodium acetate for HCl in pretreatment has been considered. The dispersion of calcareous soils complicates such a procedure. Furthermore, it is impossible to wash a Na-saturated colloid with water to remove excess electrolyte. While this washing can be accomplished with alcoholic solutions, the sodium acetate pretreatment does not at this time seem to offer an advantage sufficient to warrant its adoption.

The apparent chemical stability of the 1-μ fraction is noteworthy. Table 3 shows that in no case did HCl treatment reduce this fraction even in the calcareous soils. If it is assumed that the inorganic colloids are an end-product of weathering and hence resistant to further alteration, as seems justified, the desirability of including a sedimentation period that will determine this fraction is evident. That an equivalent diameter of 1 μ accomplishes this purpose seems to be shown by the data, and it is suggested that this limit be used in preference to the 2-μ limit.

CONCLUSIONS

The conclusions reached in the present work may be expressed in the following tentative outline of a procedure for dispersion:

1. Treat 10 grams of freshly air-dried soil with 200 cc of N/10 HCl, stirring 1 hour; or let stand overnight.
2. Wash thoroughly in a Buchner filter and transfer to a shaking bottle.
3. Shake 48 hours with 0.11% Na_2CO_3.
4. The addition or substitution of a sampling interval equivalent to 1 μ diameter is recommended.

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ARTIFICIAL TRIPPING OF FLOWERS IN ALFALFA IN RELATION TO SEED PRODUCTION[1]

JOHN W. CARLSON[2]

Considerable research has been conducted to determine the relative importance of artificial tripping in alfalfa in relation to seed production. To secure data on this point a few specially designed experiments were begun in 1926 at the Uintah Basin Alfalfa-seed Experimental Farm, at Fort Duchesne, Utah. The results secured from these studies during 1926 and 1927 have been reported in a previous paper (1).[3] Additional data have been obtained since that time, and another report, together with a summary of the data contributed by other workers, appears to be appropriate at this time.

Table 1 contains data adapted by the writer, but obtained by various investigators, bearing particularly upon the point under consideration. These data have been gathered from regions differing in climatic conditions and some in one year and some in another. In the main, the data are comparable and substantiate similar conclusions.

Piper, *et al.* (4) found that 16.76% of the alfalfa flowers set pods when developed naturally and 30.68% when tripped artificially. In ratio form this is 1:1.8 in favor of artificial tripping as compared with natural development. When the flowers were enclosed in cloth bags and not tripped by hand or by insects, 5.5% of them formed seed pods. This low percentage was thought to be due to the exclusion of insects, important as agents in tripping alfalfa flowers.

The average number of seeds in each pod was somewhat greater in the case of the naturally-developed flowers, which was attributed

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[2] Superintendent, Alfalfa seed Experimental Farm, Uintah Basin, Ft. Duchesne, Utah. The writer wishes to express appreciation for the helpful suggestions offered by Dr. George Stewart, under whose direction these experiments were conducted.

[3] Reference by number is to "Literature Cited," p. 786.

TABLE 1.—*Summary of data from various investigators showing importance of artificial tripping of flowers in alfalfa in relation to seed production.*

Treatment and time of studies	No. of flowers	Weighted average percentage of flowers forming	Average No. of seeds per pod
1908, 1909, 1910, (Piper, *et al.*, 4) Flowers enclosed and not tripped by hand	9,340	5.50	1.78
Flowers enclosed and tripped by hand	9,074	30.68	1.72
Flowers not enclosed and not tripped artificially (natural development)	8,939	16.76	2.22
1911, 1912 (Frandsen, 2) Flowers enclosed and not tripped by hand	1,345	9.30	1.30
Flowers enclosed and tripped by hand	1,215	35.60	1.70
Flowers enclosed and pollinated with foreign pollen	804	64.20	3.90
1920, 1921, 1924, 1925, (Southworth, 5) Flowers enclosed and not tripped by hand	3,890	12.80	—
Flowers enclosed and tripped by hand	3,424	46.50	—
Flowers exposed and not tripped by hand	3,101	26.40	—
Flowers exposed and tripped by hand	2,772	46.80	—
1925 (Hay, 3) Flowers not tripped by hand	960	5.94	—
Flowers tripped by hand	960	9.48	—

to some degree of cross-pollination associated with tripping by insects.

Frandsen (2), working in Denmark, obtained a ratio of 1 :3.8 in favor of artificial tripping when compared with no tripping and the flowers enclosed. His carefully controlled experiments show a ratio of 1 :6.9 in favor of cross-pollination when compared with no tripping of enclosed flowers.

Tripping in alfalfa flowers does not of necessity imply cross-pollination. Artificial tripping may be accomplished without introducing new pollen to the flowers, but artificial cross-pollination is usually accompanied by tripping. This fact may account for some of the increase in the percentage of flowers forming pods following cross-pollination. This becomes more evident when, with Frandsen's data, artificial tripping with self-pollination is compared with artificial cross-pollination. The ratio in this case is 1 :1.8 as compared with 1: 6.9 in the case of no tripping of enclosed flowers. However, all tripped flowers are exposed to conditions favoring the introduction of foreign pollen by wind, rain, insects, and other agents. Untripped flowers are well protected against being naturally cross-pollinated, except possibly with the aid of small insects which are capable of passing between the petals of the flower without releasing the tripping mechanism.

Frandsen found no significant difference in the average number of seeds formed in each pod from the untripped and the artificially-tripped flowers. Cross-pollination, however, produced a gain of 246% in the average number of seeds formed to the pod. These results serve further to distinguish between the phenomena of tripping and cross-pollination. They also support Piper's conclusion that cross-pollination is more potent than self-pollination in alfalfa.

Southworth (5), working in Canada, obtained a gain in the percentage of flowers forming pods in the ratio of 1:3.6 in favor of artificial tripping when compared with no tripping and the flowers enclosed. These results are practically identical to those obtained by Frandsen under similar conditions. When the flowers were left exposed and not tripped artificially the gain was 1:1.7 in favor of artificial tripping. These results agree perfectly with those secured by Piper under similar conditions. Southworth also compared flowers artificially tripped and left exposed with others artificially tripped and then enclosed. The percentage of flowers forming pods was about the same in both cases, or 46.8 and 46.5%, respectively. It appears that tripped flowers are not so easily influenced by a change in the external environment, such as is produced by enclosing the flowers. It is also evident from these data that natural development is more favorable for pod development than having the flowers enclosed and not tripping them.

Hay (3), in a preliminary report of his work in Canada, found a low percentage of flowers forming pods. However, his ratio of 1:1.5 in favor of artificial tripping when compared with natural development is significant in the light of other researches.

EXPERIMENTAL WORK

The methods and technic used by the writer to continue the studies of the alfalfa flowers are the same as those described in a previous report (1). After 1926 the seasons were divided into four or five periods, at the beginning of which a new set of flowers was labelled for observation. For each set 10 representative locations were chosen on the plats of the experimental farm. At each location five pairs of racemes were numbered 1 and 2, 3 and 4, and so on to 10. Small tags attached to the base of the racemes were used as markers. Both members of a pair were always located on the same secondary branch of the mother plant, but the different pairs at each location were not always placed on the same plant. In selecting a pair, the object was to get two racemes with flowers as nearly equal in number as possible and nearly in the same stage of development. In this way each member of any one pair was exposed to the same environmental conditions.

The flowers on the racemes marked with the odd number of a pair were allowed to develop naturally after all wilted ones had been removed with a pair of scissors and the remainder counted. Daily observations were made of the flowers for a few days to determine the number that had become tripped. The standard was clipped from all tripped flowers. This method of branding provided against the flower being counted a second time on subsequent visits. The daily visits were continued until the flowers had formed green pods or had become stripped. In this way accurate data were obtained on the number of the flowers that became tripped under natural conditions of development and on the number that formed pods.

The flowers on the racemes marked with the even number of a pair were tripped artificially, after all wilted flowers and unopened buds had been removed and the remainder counted. Tripping was accomplished by inserting a pencil point into the throat of the corolla. All the flowers on the same raceme were tripped in succession. No effort was made to prevent the pollen from one flower being carried to another. Some cross-pollination is likely to have occurred in the tripping process. Since all wilted and unopened flowers had been removed, the remainder could be tripped on the same day It was not necessary to return to do more tripping upon successive days. However, a daily observation was made of the flowers to insure their being in a tripped condition. Almost without exception, flowers tripped on one day would be found with wilted petals the following day. Artificial tripping seemed to hasten the process of pod formation.

Table 2 contains in summarized form the data for each season. In 1926, 25.6% of the alfalfa flowers set pods when allowed to develop naturally and 56.6% when tripped artificially. In ratio form, this is 1:2.2 in favor of artificial tripping. In 1927, an average of 39.1% of of the flowers that developed naturally formed seed pods and 65.8% when tripped artificially. The ratio is 1:1.6 in favor of artificial tripping. These results agree closely with those obtained by Piper, Frandsen, and Hay under similar conditions. The season of 1927 was not characterized by extremes in meteorological conditions or by an erratic behavior of the alfalfa flowers. An excellent crop of seed was produced during this year.

TABLE 2.—*Summary of data showing importance of artificial tripping of flowers in alfalfa in relation to seed production, Uintah Basin, Utah.*

Treatment	No. of flowers	Weighted percentage Tripping naturally	average of flowers Forming pods	Range in average percentage of flowers forming pods by periods in season
		1926		
Flowers not enclosed and not tripped by hand (natural development)	740	6.2	25.6	
Flowers not enclosed and tripped by hand (artificial tripping)	795		56.6	
		1927		
Natural development	3,740	11.7	39.1	36.8 to 41.5
Artificial tripping	2,942	—	65.8	63.2 to 68.4
		1928		
Natural development	8,310	8.2	22.0	12.4 to 30.4
Artificial tripping	6,560	—	69.3	64.6 to 74.0
		1929		
Natural development	3,751	6.4	10.1	4.5 to 21.5
Artificial tripping	3,447	—	43.0	20.1 to 57.2
		Summary		
Natural development	16,541	8.1	24.2	—
Artificial tripping	13,744	—	58.6	—

In 1928, an average of 22.0% of the flowers formed seed pods when developed under natural conditions and 69.3% when tripped artificially. The ratio is 1:3.1 in favor of artificial tripping. This season was not so favorable for seed production as 1927 had been. Rather wide fluctuations in the percentage of flowers forming pods occurred from one period to another. This is especially true of flowers that were allowed to develop under natural conditions. The season of 1929 was even more unsatisfactory for seed production. An average of 10.1% of the flowers developed under natural conditions formed seed pods and 43.0% of those tripped artificially. This is a ratio of 1:4.2 in favor of artificial tripping. During 1929, the absolute percentage of flowers forming pods was lower than that of any other year from which data have been gathered. Greater irregularity in the behavior of flowers tripped artificially was also shown at this time.

It would appear from the data presented that artificial tripping in alfalfa results in greater stability and regularity in the subsequent behavior of the flowers. Mention has been made of the fact that the fluctuations in the percentage of flowers forming pods are greater in the case of flowers developing naturally than those tripped artificially. Although, as stated, the absolute percentage for 1929 is less than for any other year, the flowers tripped artificially in general appear to be influenced by changing external conditions to a lesser degree than are flowers developing under natural conditions. Southworth (5), also, has shown that flowers after being tripped artificially form seed pods as readily when enclosed as when exposed. This was found not to be the case with untripped flowers.

TABLE 3.—*Effects of natural development and artificial tripping in relation to development of pods and seed to normal maturity.*

Treatment	Percentage of pods formed attaining normal maturity	Average No. of seeds per pod
	1926	
Natural development	41.0	Data not taken
Artificial tripping	37.3	Data not taken
	1927	
Natural development	88.9	2.94
Artificial tripping	91.0	2.25
	1928	
Natural development	82.4	2.74
Artificial tripping	80.8	2.73
	Summary (by weighted averages)	
Natural development	70.7	2.84
Artificial tripping	69.7	2.49

In Table 3 data are given which show the effects of natural development and of artificial tripping in relation to the ability of the pods formed to develop to normal maturity as well as to the average number of seeds to the pod. The weighted averages in the summary show no significant differences in either of these characters. It is evident, therefore, from these data that artificial tripping produces no injurious effects which influence the normal development of the pods and seed in alfalfa. Seed pods formed as a result of artificial tripping are fully equal to those formed under natural conditions. This method, therefore, may be expected to result in a yield of seed proportional to the increase in the number of pods formed.

The writer's data show that only a relatively small part of the flowers that develop naturally become tripped, either automatically or through the aid of insects. It appears, therefore, that in the Uintah Basin (Utah) alfalfa flowers are capable of setting pods rather freely in the absence of tripping.

These researches have been made to determine the effects of artificial tripping of alfalfa flowers in relation to seed production. No attempt has been made to discover methods of effecting the tripping in a manner that might be important economically. The latter problem suggests some interesting possibilities.

SUMMARY

1. Data regarding the effect of artificial tripping of flowers in alfalfa seed production are herein summarized.

2. In the main the data are comparable and substantiate the conclusion that on the average artificial tripping will increase the per-

centage of flowers forming pods in the ratio of 1:2.5 as compared with natural development.

3. Seed pods formed as a result of artificial tripping attain to normal maturity and are fully equal to those formed under natural conditions.

4. It would appear from the data presented that artificial tripping in alfalfa results in greater stability and regularity in the subsequent behavior of the flowers. When being considered for seed production, untripped flowers seem to be more easily influenced unfavorably by changes in the external environment of the flower.

5. No attempt has been made to discover methods of effecting the tripping in a manner that might be important economically. This problem suggests some interesting possibilities.

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HYBRID INTENSIFICATION OF PLANT HEIGHT IN COTTON AND THE RELATIONSHIP OF NODE NUMBER AND INTERNODAL LENGTH TO THE PHENOMENON[1]

J. O. WARE[2]

Marked hybrid vigor or intensification is expressed in certain organs or parts of the cotton plant when some of the species are crossed, but no pronounced display of the phenomenon is known to appear for any of the characters when the crosses are made among varieties within a species.

Balls (1)[3] on hybridizing species observed intensification in many characters. The more obvious evidence of the trait was shown in plant height, time of flowering, length of lint, and size of seed. In this connection, he says, "The most striking feature is the intensification of certain characters which results when two botanically dissimilar cottons are crossed together."

Cook (4) crossed Kekchi, a Guatemalan cotton similar in type to the Upland (*Gossypium hirsutum*), with Egyptian (*G. barbadense*) and secured in the conjugate generation intensification of several characters. On the other hand, no extra vigor was shown when Kekchi and Upland were crossed, but rather a weakened or suppressed condition of the characters studied. Cook says, "Increased vigor and fertility are commonly found in crosses between narrow strains, the so-called 'elementary species' or 'biotypes' used in Mendelian experiments, but such crosses of closely related varieties of cotton do not appear to give any such definite phenomena of intensification as do hybrids between widely different types." He also says, "Suppression and intensification of characters are most pronounced in the first generation and tend to disappear in later generations."

Kearney and Wells (7) found no intensification in crosses between Egyptian varieties. The writer, in genetical studies of several qualitative characters which involved extensive crossing among Upland varieties, did not observe any pronounced increase of vigor in either conjugate or perjugate hybrids.

Brown (3) reported hybrid vigor from a cross of two inbred strains coming from the same variety. The strains, however, had been selfed for three generations and showed decreased vigor. Heterosis

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[3] Reference by number is to "Literature Cited," p. 801.

as obtained by this investigator may have been more attributable to restoration in normal vigor than to intensification in the sense of expression extending beyond that naturally existent in the variety. The condition seems to be similar to that heretofore referred to by Cook as vigor in crosses between narrow strains.

Since information on hybrid intensification in cotton was rather meagre, a breeding experiment was begun at the Arkansas Agricultural Experiment Station in 1921 to make a study of this phase of cotton genetics. Egyptian and Upland cottons were crossed in view of the fact that little or no intensification is shown in varietal crosses of the same species. These two sorts of cotton are also American grown The Egyptian type was showing considerable economic progress in the Southwest at the period when this work was started. Data on all the observable characters of the cross were taken, but the object of this paper is to present the results in plant height and the relationship of node number and internodal length to the enhancement of the character in the hybrids only.

Previous to the inception of the Arkansas experiment, Balls (2), working in Egypt with an Upland X Egyptian hybrid, in reporting hybrid vigor, had spoken of the relationship of node number and internodal length to plant height. While the work was in progress, Kearney's (6) publication appeared giving results of the Holdon (Upland) X Pima (Egyptian) hybrids. This investigation indicated that the character magnitude of the F_1 in relation to the respective allelomorphic pairs ranges in degree from that of intensification above the greater parental character, in some cases, down through full dominance to an intergrade state between the two parental characters, in other cases. Among the 39 characters studied in the Holdon-Pima cross, plant axis length, internodal length of the main stem, leaf length, leaf width, pedicel length, bract length, corolla length, and pistil length of the F_1 population exceeded that of the greater (Pima) parent.

Determinations such as reported in Kearney's paper on plant height and node number were those sought in the Arkansas work. However, there appeared to be some vitiating factors in the Holdon-Pima experiment. An entirely different type of Upland cotton from that of the Holdon variety was also used in this study. Kearney (6) states, "It is regrettable that the F_1 progeny of the hybrid grown in 1919 was not of adequate size for comparison with the F_2 population of that year. The F_1 grown in 1920 was perforce used for this purpose, but the validity of the comparison is lessened not only because of the probable effect of different weather in the two seasons, but also because the F_1 progeny of 1920 was situated on better soil than that upon which the Pima and Holdon parental progenies and the greater part of the F_2 population in 1919 were grown. This makes the comparison unsatisfactory, especially in regard to size characters." The number of plants grown for the populations in the Holdon-Pima work was rather small for quantitative inheritance studies. Kearney also did not report any back crossing.

The Arkansas experiment was more inclusive than the Holdon-Pima experiment and was so conducted as to eliminate or reduce to a minimum the seasonal and soil variables. Each population included more plants, with the exception of the Pima parental strain, than occurred in Kearney's studies. Back cross progenies were grown, which is an important step in hereditary studies and should always be included. The difference in the type of Upland plants used in the two experiments is an important consideration. In the Holdon-Pima hybrids, the plants of the Holdon variety were much shorter than the Pima plants, while the Upland variety used in the Arkansas experiment was nearly equivalent in height to the Egyptian type. Similarity in height eliminates the effects of contrasting allelomorphs. In this case hybrid vigor would hardly be considered intensified dominance.

MATERIALS AND METHODS

The Pima variety, the same as used by Kearney, was the Egyptian type employed in the Arkansas experiment As heretofore referred to, the variety representing the Upland type was quite different from that included in the Holdon-Pima hybrids. The Holdon variety is characterized by short, bushy, stocky plants much lower in stature than the Pima plant, while the Upright variety, very similar to Shankhigh and sometimes called Hastings Upright, has a tall slender axis with short zig-zag jointed fruiting limbs clinging closely to the main stem. An occasional plant with a large vegetative side branch may occur in the Upright. A typical Upright plant with a Pima plant and the F_1 from the two as parents are shown in Fig. 1.

In a study of hybrid vigor there is a distinct advantage in using characters of similar magnitude for the cross. The phenomenon of dominance plays no part in the F_1 intensification nor does the expression of one allelomorph, where there is tendency of dominance, overshadow, in subsequent generations, that of the other. Any increased vigor on the part of plants beyond the conjugate generation can not be attributed to segregating dominants, but to the transmission of the heterosis complex alone.

Crosses were made between two Pima plants used as females and one Upright plant used as the male. This original crossing was done in 1921 of pure strains that had been previously selfed. As the pollinations were being made, the plants used in the crosses were selfed. In 1922, F_1 generation and parental strain plants were selfed for the 1923 planting. Also new F_1 crosses designated as recrosses from parental strains were made. The current F_1 was crossed back on both parental strains. These re-crosses and back crosses were made with plants that were being selfed for the next year. The third generation of the selfed parental strains, the F_1 generation (re-crosses), the progeny from both backcrosses, and the F_2 generation (from the original F_1 progeny) were all available for taking the data in 1923.

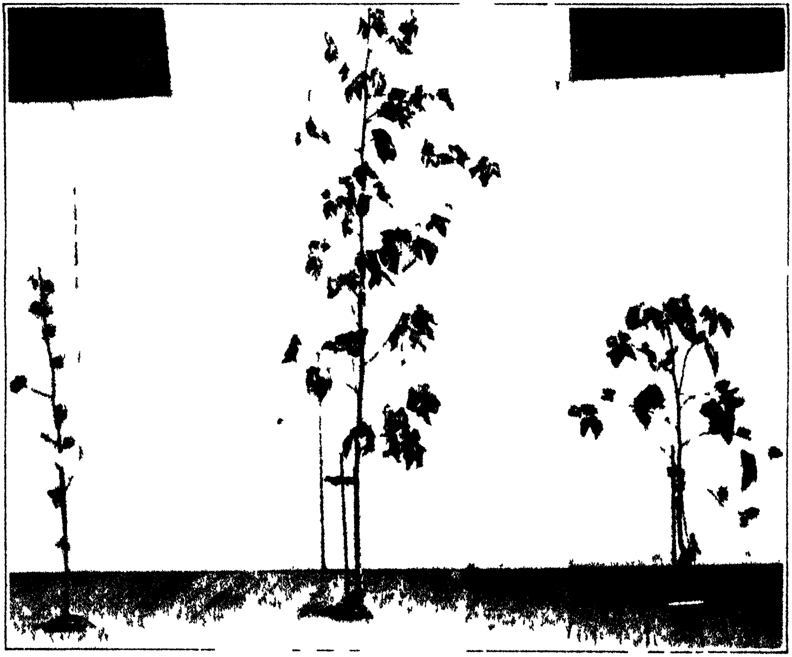

FIG. 1.—*Left*, Upright parental plant. *Right*, Pima parental plant. *Center*, F_1 hybrid (Pima x Upright) showing intensifications.

The soil upon which these breeding trials were conducted was uniform in texture, in fertility, in respect to previous cropping, and in respect to husbandry. Plants raised for comparative study should be produced under the same seasonal conditions and on the same soil, if reliable results are obtained. In a study of the inheritance of plant height or any other plant size character, the reliability of the genetical findings could be considerably upset by minute variations in the physiological processes of individual plants caused by differences in soil, season, or culture.

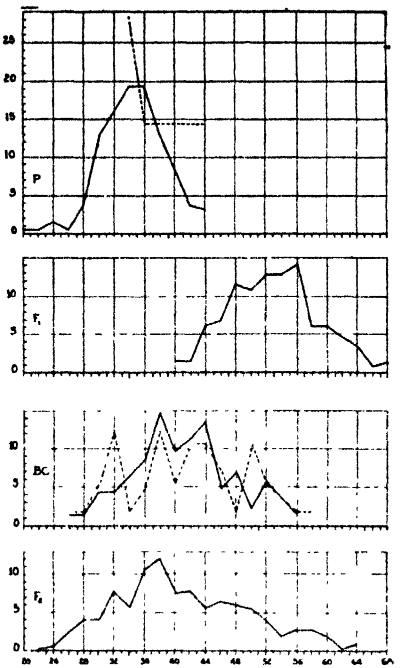

FIG. 2.—Height of plant, Pima x Upright. The ordinate numerals indicate the number of plants as a percentage of the total population. The abscissa numerals denote the height of plant in inches. The solid curve line in the P section of the graph represents the Upright parental population and the broken angled line, the Pima parental population. The solid curve line in the B C section of the graph represents the population from the back cross on the Upright parental strain and the broken curve line the population from the back cross on the Pima parental strain. What the curves in the F_1 and F_2 sections show is obvious.

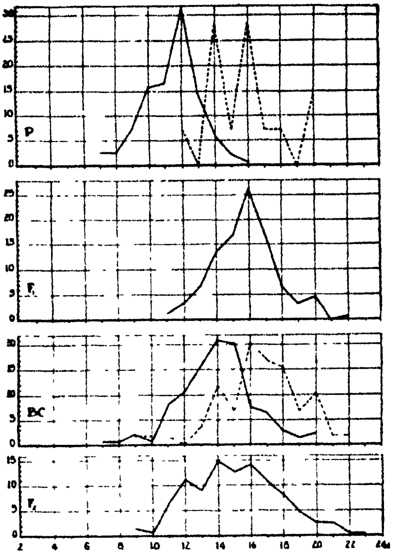

FIG. 3.—Node number, Pima x Upright. The ordinate numerals indicate the number of plants as a percentage of the total population. The abscissa numerals denote the number of nodes. The solid curve line in the P section of the graph represents the Upright parental population and the broken curve line the Pima parental population. The solid curve line in the B C section of the graph represents the population from the back cross on the Upright parental strain and the broken curve line the population from the back cross on the Pima parental strain. What the curves in the F_1 and F_2 sections show is obvious.

METHOD OF SCORING RESULTS

Plant height measurements in inches and node counts were taken on each plant of all generations in the 1923 growth. These determinations were made at the close of the growing season.

The plant height and the node count data are each grouped into six populations, the Pima parental strain, the Upright parental strain, the F_1 generation, the back cross of the F_1 on the Pima parental strain, the back cross of the F_1 on the Upright parental strain, and the F_2 generation. The frequency distributions and statistical constants of the six populations with reference to plant height are given in Table 1. A similar presentation for node number is shown in Table 2. The frequency distribution for the six populations in plant height are plotted graphically and shown in Fig. 2. The frequency distribution curves for the nodes of the same populations are given in Fig. 3. The frequency curve of each respective population is based upon a percentage frequency. The number of plants in a given class

TABLE 1.—*Frequency distribution of individuals in height of plant in inches for the six Pima-Upright parental and hybrid populations.*

Height in inches	Pima parental strain	Upright parental strain	F_1 generation	Back cross on Pima	Back cross on Upright	F_2 generation
68			2			
66			1			
64			5			3
62			7			1
60			9			7
58			9	1		10
56			21	1	2	10
54			19	2	5	7
52			19	3	8	14
50			16	6	3	19
48			17	1	10	21
46			10	4	7	22
44	2	6	9	6	19	19
42	2	7	2	6	16	27
40	2	16	2	3	14	26
38	2	24		7	21	42
36	2	36		4	12	37
34	4	36		1	9	20
32		24		7	6	24
30		24		3	6	14
28		7		1	2	14
26		1		1	2	9
24		3				2
22		1				1
20		1				
Number	14	186	148	57	142	349
Mean	38.29 ± .651	34.69 ± .215	53.00 ± .324	41.37 ± .694	41.08 ± .377	41.24 ± .318
S. D.	3.61 ± .460	4.34 ± .152	5.84 ± .229	7.77 ± .491	6.66 ± .267	8.82 ± .225
C. V.	9.43 ± 1.202	12.51 ± .437	11.02 ± .432	18.78 ± 1.181	16.21 ± .649	21.39 ± .546

is expressed in a percentage of the total number of plants in the population. The frequency distributions in the tables show the actual numbers of plants. The tables also give the number of individuals in each population and the population means, standard deviations, and coefficients of variability.

TABLE 2.—*Frequency distribution of individuals in node number for the six Pima-Upright parental and hybrid populations.*

Node number	Pima parental strain	Upright parental strain	F_1 generation	Back cross on Pima	Back cross on Upright	F_2 generation
23						1
22			1	1		1
21			0	1		9
20	2		7	6	3	9
19	0		5	4	2	17
18	1		10	9	4	28
17	1		25	10	9	37
16	4	1	39	12	11	49
15	1	4	25	4	29	44
14	4	11	20	7	30	52
13	0	27	10	2	23	31
12	1	59	5	0	15	38
11		31	2	1	12	22
10		29		1	1	2
9		14		1	3	8
8		5			1	
7		5			1	
Number	14	186	149	59	144	348
Mean	15.85± .402	11.40± .085	15.79± .109	16.56± .223	14.01± .128	15.04± .099
S. D.	2.23± .284	1.71± .060	1.97± .077	2.54± .158	2 27± .090	2.73± .070
C. V.	14.07± 1.793	15.00± .525	12.48± .488	15.34± .952	16.20± .644	18.15± .464

The nodes were counted on each plant that was measured fo height. However, it will be noted in the tables that the number c individuals in some of the populations are not identical for both measurements and node counts. This disparity is due to some of the individuals going out of the bounds of what seemed to be the natural frequency distribution or the accidental dropping of an individual in adding the arrays of frequencies from the original data. One plant, through an error, was omitted for plant height in the F_1 generation. One plant went out of bounds on each side of the frequency distribution for plant height in the population from the back cross on the Upright. Two plants went out of bounds on the upper side of the distribution for plant height in the population from the back cross on the Pima. One plant went out of bounds on the upper side of the distribution for node number in the F_2 population.

The relationship of internodal length to the intensification of plant height or the inheritance of axis length is arrived at by comparing the results of the height measurements with the results of the node count.

HEIGHT OF PLANT

The mean height of the Upright parental strain was 34.69 ± .215 inch and that of Pima parental strain 38.29±.651 inches, a difference of 3.60 ± .685. The mean height of the F_1 population was 53.00 ± .324, or 14.71 ± .727 inches taller than the mean of the higher (Pima) population. Fig. 1 does not indicate the same proportions in height for the parental strains and the F_1 hybrid as the actual measurements show. The picture represents the Upright plant to be slightly taller than the Pima plant and the Hybrid plant almost twice as high as either parental individual. It must be borne in mind, however, that the specimens selected for photographing were picked by inspection as apparently best representing the types before the data were calculated.

The number of individuals in the Pima population was not sufficiently large to constitute a graph taking more nearly the form of a curve of error, but observation on many such plants of sister strains seemingly indicates that variability in this race is not pronounced. The measurement of a larger sample in the Pima variety would have established a better frequency curve, but no doubt would have shifted the mean very little. Even though the number of plants in the Pima population was small, the fluctuation was much less than with the Upright population. The coefficient of variability of the former was 9.43 ± 1.202, while the latter was 12.51 ± .437. None of the plants of the Pima strain were taller than the highest Upright plant, while practically one-third of the Upright population ranged lower in stature than any of the Pima plants. The low swing in the frequency distribution of the Upright population is responsible for the failure of the mean of this parental strain to coincide practically with the mean of the Pima parental strain. This divergence was also the cause of the larger coefficient of variability in the Upright group. However, there was not enough difference between the height of the two parental types for dominance or segregation to interfere with the detection of hybrid intensification, if this characteristic and dominance are distinguishable as separate entities.

Pronounced intensification was shown in the F_1 generation. This trait was so marked that only 13 plants out of the 148 conjugate plants were no taller than the parental plants. The slight overlapping of the F_1 distribution as shown in the curves of Fig. 2 coincided with the three highest classes in the parental group.

In the F_1 population, according to the coefficient of variability, the plants fluctuated somewhat more than in the Pima parental strain and somewhat less than in the upright parental strain. The hybrid constant occupied approximately an intermediate position between those of the parents. In Kearney's (6) work, the coefficient of variability is less for the F_1 than for either parental strain. His constants are for F_1, 8.1; for Pima, 11.1; and for Holdon, 13.2. The Holdon-Pima hybrids involved dominance. The height of the Pima mean was much greater than that of the Holdon. The lesser tendency to vary innate in the Pima stock probably reduced the variability in the conjugate generation of the Holdon-Pima work. By the nature of this experiment, tallness overshadowed what variability might have been transmitted from the Upland parent. Kearney's F_1 population was grown in a different year from when his parental strains were raised, and the F_1 plants occupied better soil than was employed for the growth of the parental strains. Variability comparisons of plants from separated situations such as indicated can not be very trustworthy.

East (5) says, "Crosses between individuals belonging to races, which from long continued self-fertilization or other close inbreeding approach a homozygous condition, should give F_1 populations comparable to the paternal races in uniformity." Since the Upright and Pima plants had been selfed for two years before recrosses were made, and, in view of the fact that these races remained pure in subsequent generations, it is not probable that the greater diversity of the F_1 population over one parental strain is due to heterozygosity for height.

In looking through the literature on hybrid vigor and intensification in cotton not a single case was located where two characters of the same magnitude were used to study the comparative diversities of the parental races and the F_1 offspring. Uniformity in the F_1 population comparable to that of the parental types according to many workers should hold where contrasting allelomorphs are crossed, but what should the result be where the characters are practically identical? The coincidence in height of the Upright and Pima plants may not theoretically produce a conjugate generation as uniform in height as either race. There are no stabilizing effects of dominance. The enhanced vigor of the F_1 plants may have rendered the constitutions of these individuals more sensitive to minute influences of environment.

Balls (2) in his Sultani-King cross obtained considerable plant height intensification in the early season, but in the late season the F_1 plants assumed an intergrade position between that of the parental strains. This alteration was due to a change in the rate of growth. Thermotoxy, which occurs in Egypt, seemed to affect the two parental strains and the F_1 differently. The main stem of King after midseason practically discontinued elongation. The speed of growth of the central axis of the F_1 plants was considerably retarded after midseason, but plant height with the Sultani almost constantly increased until the end of the growing period.

The data on the Arkansas experiment were taken at the close of the growing season. The location at Fayetteville, where the plants were grown, is just outside of the northern rim of the territory of commercial cotton production. Upright is not an extremely early variety like King. Upright matures a little ahead of Pima and the latter makes sufficient development to produce several normal open bolls before the frost or cool fall nights cause a cessation of growth. Under a climate of longer seasons in central Arkansas, the Upright grew as late as the Pima did. There were no weather vicissitudes at Fayetteville as was the case in Egypt to upset the growth of one parental strain more than the other or the parental strains more than the progeny generations as far as height was concerned.

The back crossing involved a case of cross pollinating plants of considerable difference in height. If it were not known that the extra height of the F_1 plants was the result of the heterosis complex, these plants might be assumed to be sufficiently contrasting in the matter of tallness for material to study the inheritance of axis length. Since the parental strains were apparently homozygous for height and approached practically the same magnitude in this respect, and since the much taller condition of the F_1 generation was due to intensification alone, the back cross progenies would not be expected to segregate. The question as to whether the sesqui-hybrids are as tall as the F_1 hybrids depends upon whether or not heterosis is passed on undiminished. Fluctuation also would not be expected to be greater in the back cross progenies than in the conjugate generation. Neither the progeny from the back cross on the Upright nor the progeny from the back cross on the Pima seemed to segregate. The notched appearance in the graphs, representing these distributions, is probably entirely due to oscillating tendencies caused by environmental differences. Larger numbers of individuals, no doubt, would have considerably smoothed the curves. The curve of the back cross on the Upright is represented by more plants than the back cross on the Pima and is less jagged in appearance than the latter.

Another indication of the lack of segregation in the back cross progenies or the absence of dominance in these sesqui-hybrid plants is the coincidence of the two distributions. The curves in Fig. 2 show the one superimposed upon the other. A wider fluctuation is an indication of segregation, however. This tendency was more pronounced in both back crosses than it was in that of the F_1 generation. The coefficient of variability of the F_1 population was 11.02 ± .432, of the back cross on the Upright 16.21 ± .649, and of the back cross on the Pima 18.78 ± 1.186. When two botanically dissimilar cottons are crossed, there is a tendency for the plants in generations beyond the first filial to fluctuate in many respects. Some of the plants become partially sterile, others completely sterile, and still others take on somewhat abnormal tendencies in certain vegetative parts. These segregating forms probably are in no way connected with the factors for height determination, but the upsetting of other functions in the plant to a certain extent disturbs the normal growth of axis length. These outcroppings rarely appeared in the back cross on the Upright, but they were somewhat more in evidence in the back cross on the Pima and the F_2 generation. The fluctuations were increased as the abnormalities became more numerous. This peculiarity, no doubt, is chiefly responsible for the greater variability in the subsequent generations, particularly in the progeny from the back cross on the Pima and the F_2 generation. Segregation of factors for tallness hardly obtained.

The abnormality tendency was so great in the germination of the F_2 seed and the growth of the F_3 that height studies with these crosses were not carried further. Kearney (6) had similar experiences with the Holdon-Pima hybrids.

The position of the frequency distribution of the two back cross populations is chiefly due to the influence of intensification. These two populations take an upward swing, but do not hold a place as prominent in the upward scale as the F_1 population. Considerable regression has set in. The means and the position of the frequency curves show these back cross progenies to be less tall than the F_1 progeny.

Due to the similarity of height in the two parental strains, the F_2 generation was not expected to segregate for axis length, however there is a wide dispersion in its population. The extent of the F_2 fluctuation almost fulfills East's (5) requirements as necessary to establish the fact of segregation. The only limitation is the lack of deviation beyond the lower limits of the range of the Upright parental strain. The spread of the frequencies should not be explained upon the basis of height factor segregation, but as being secondarily affected by the splitting out of characters which, because of the nature of their effect on the processes of the plant, militate against the normality of height. Oscillating fluctuations not only played a part in the F_2 generation, but affected all populations. However, where no systematic errors occur, it is reasonable to expect that sufficient numbers will overcome the effects of variation due to chance. The F_2 population frequency distribution gave a smoother curve than either back cross progeny population. This is expected since the number of individuals is larger.

The position of the F_2 frequency distribution probably is due more to the transmission of the heterosis complex than to any other influence. The mean of the F_2 generation stands practically at the same level of the means of the two back cross progenies. However, the curve shape of the F_2 generation seems to indicate some tendency of the force of hybrid vigor to wane. The peaking of the F_2 population within the range of the parental frequencies shows a regressive movement toward the normal parental height.

NODE NUMBER

The node number was larger in the Pima variety than in the Upright variety. The mean number in the former was 15.85 ± .402 and in the latter 11.40 ± .085. The frequency distributions, as shown in Table 2 and in Fig. 3 overlapped, however. The upper extreme of the Upright fluctuation ascended slightly beyond the mean point in the Pima distribution and the Pima fluctuation descended nearly to the mean point of the Upright distribution. The curve shows the Pima population to be more erratic than the Upright population. However, the coefficient of variability was slightly less for the Pima parental strain than for the Upright parental strain. As heretofore stated, the number of Pima plants was small. A larger number, no doubt, would have given a smoother curve.

The difference between the mean node number of the two parental populations was 4.45 ± .411. There was probably sufficient spread between the parental means to detect whether or not dominance transmission was taking place. The height of the two races were too nearly equivalent for dominance activity, provided it was functioning, to be observed. The F_1 generation, according to the coefficient of variability, was more uniform than either parental strain. The actual spread of the frequency of the F_1 population, however, was wider than that of the Pima population. One plant of the former group contained two more nodes than the number borne by the two plants in the highest class of the latter group. Two F_1 plants had one less node each than was possessed by the plant in the lowest class of the Pima group.

No intensification appeared in the F_1 offspring, except in the case of the one plant referred to in the previous paragraph. The F_1

merely demonstrates a case of practically complete dominance. The three plants that went out of range of the Pima parental distribution are only one class interval beyond the Pima limits. The means of the two populations practically coincide. The F_1 mean is 15.79 ± .109 and the Pima mean 15.85 ± .402. The difference is only 0.06 ± .416 and negligible.

The position of the frequency distribution of the F_1 population with respect to nodes, as compared with height, shows that intensification in height was all a case of the lengthening of the internodes and not a matter of additional nodes.

A comparison of the positions of the two sesqui hybrid distributions (Fig. 3) shows a tendency for these two populations to diverge. The progeny of the backcross on the Upright shifts somewhat away from the center of the F_1 distribution and to a degree into the area of the distribution of the Upright parental strain. The progeny of the back cross on the Pima bulges slightly higher than the area occupied by the F_1 distribution. The mean of the progeny from the back cross on Upright occupies a position lowered to a point almost halfway down to the parental Upright mean. The mean of the population from the back cross on Pima occupies a position somewhat beyond that of the F_1 population. The lowest frequency limit of the Upright back cross coincided with the lowest frequency of the Upright parental strain, and the highest frequency limit coincided with the highest frequency of the Pima parental strain. The lowest frequency limit of the Pima back cross approached, within two class intervals, the lowest frequency of the Upright parental strain and the highest frequency limit coincided with the highest frequency of the F_1 population which is two class intervals beyond the upper limit of the Pima parental strain. The plants of either back cross population as a group were somewhat more variable than in the F_1 population. The curves of these populations as well as their coefficients of variability indicate this condition. Both back cross distributions were unimodal. However, the offspring of the back cross on the Pima exhibited some notching.

As compared with the F_1 population, the back cross populations with their larger coefficients of variability, their wider frequency bases, their somewhat notched curves, and their tendency to diverge indicate segregational activity. The bulge of the curve formed by the population from the back cross on the Pima, to limits somewhat beyond the upper curve outline of the distribution of the Pima parental strain, may be an indication of hybrid vigor, but it is more likely to be the activity of dominance transmitted from the F_1. The spread of the back cross curves into the region of lower node counts shows a tendency for plants with fewer nodes or the recessive number to outcrop. The upward spread of these curves is caused by the dominance of higher numbers. Hybrid vigor for plant height, although in a somewhat waned condition, persisted in both of these back cross populations. No segregating tendencies for height were shown. The extension of internodal length, irrespective of node number, compensates for the lack of correlation of the two characters under study.

To indicate segregation when the F_2 distribution is unimodal, according to East (5), the frequencies must extend beyond the extremes of both parental strains and must show more variability than exhibited in the F_1 generation. The F_2 population does show greater fluctuation than in the F_1 and slightly more than indicated in the back cross progenies. This distribution also extends beyond the upper limits of the Pima parental strain, the F_1 generation, and the back cross progeny from the Pima, but it does not extend entirely to the lower limits of the Upright parental strain. However, the downward swing seems sufficient to indicate some segregation, particularly in view of the fact that splitting tendencies were demonstrated in the back crosses.

Strong dominance activity was in evidence throughout the back crosses and the F_2 generation and a possibility of some inkling of heterosis, although the probability of hybrid vigor was so slight for node number that intensification in height can be almost entirely attributed to lengthening of the internodes. The position of the F_2 mean at the 15.04 ± .099 node number shows a strong tendency for complete dominance of higher numbers over lower numbers. The unimodal condition of the back cross and F_2 curves indicates that several factors are responsible for node number. Internode length seems to be influenced by a different set of factors from that of node number, or if by factors common to both characters, one set is differently influenced by modifiers.

SUMMARY

Intensification of plant height in the F_1 generation was very marked. Hybrid intensity was transmitted to both sesqui-hybrids and the F_2 generation, although the vigor waned somewhat from the conjugate generation to the back cross progeny and from the back cross generation to the F_2 population. The reversed swing in the back cross and the perjugate offspring may be attributed to Galtonian regression toward the average of the races, to a weakening of the height growth due to an upset in the normal function of some of

the plants caused by the crossing of species, and probably to the segregating tendencies of height genes. However, a splitting for height would hardly be expected in offspring of parental plants so nearly equal in axis length.

The difference between the node numbers of the two parental strains was greater than the divergence in height. The curves for node number indicate distinct distributions which is not true for height of plant. The distributions for both parental strains lay within the same limits for height. The contrast of height allelomorphs was not sufficient for the detection of dominance activity. Many of the Upright plants were just as tall as the Pima plants and *vice versa.* One group could not overshadow the other. On the other hand, the contrast of the allelomorphs for node number was wide enough to get a measure of dominance. Node number in the F_1 generation expressed full dominance and no intensification. The sesqui-hybrids and the F_2 generation gave more indication of segregation for node number than they did for plant height.

The paths of hereditary transmission of plant height, on the one hand, and that of node number, on the other, followed different courses. The axis length was much intensified in the F_1 generation and then tended to regress, with an increase in fluctuation, to the average of the parental races. The node number assumed a position of full dominance in the F_1 generation, diverged into the two respective groups in the sesqui-hybrids, and formed a unimodal distribution in the F_2 generation. The adjustments of plant height and node number, although the two characters were following different routes of inheritance, were made by the flexibility of the internodal lengths of the plants. Hybrid intensity was due to an increase in the lengths of internodes and not to additions of joints or nodes plus internodes.

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THE REACTION OF ALFALFA VARIETIES TO BACTERIAL WILT[1]

S. C. SALMON[2]

Bacterial wilt of alfalfa (*Aplanobacter insidiosum* L. McC.) is by far the most important disease of alfalfa in Kansas and no doubt has been an important factor in the reduction of the acreage of this legume which, at present, is scarcely more than 50% of what it was 15 years ago. As pointed out by Jones and McCulloch (2),[3] Jones (3), Jones and Weimer (4), and by Melchers (5), to whom we owe all or nearly all of our knowledge concerning this disease, there is no known dependable method of control. Hence, any information that suggests means by which losses may be reduced should be welcome. In a series of studies at the Kansas Experiment Station projected for other purposes, considerable evidence pointing to differences in varietal resistance to this disease has been obtained. While this evidence is by no means conclusive, or as complete as might be desired, it nevertheless seems to be worthy of presentation.

All data pertaining directly to varietal reaction to this disease have been secured from field plantings. These have consisted of (a) a varietal test of 15 varieties and regional strains at Manhattan, and (b) comparative tests of Grimm and Kansas Common at five experimental fields in southeastern Kansas and on a number of farms in eastern Kansas in cooperation with farmers.

OBSERVATIONS AT MANHATTAN

The observations at Manhattan have been limited to 14 varieties seeded in duplicate and to 1 variety, Kansas Common, in replicated twentieth acre plats in the fall of 1922 In general, a good stand was secured and maintained until the spring of 1926. Early in the spring of that season, it was observed that considerable losses in stand had occurred since the preceding fall and the number of dead plants was determined by actual count. Early in May of the same year, plants

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[2] Professor of Farm Crops.

[3] Reference by number is to "Literature Cited," p. 810.

infected with bacterial wilt were found in abundance. There appeared to be marked varietal differences and an attempt was therefore made to determine the percentage of infection for each variety. For this purpose, plants from a narrow strip across one end of each plat were dug up and examined. The records of infection secured were not entirely satisfactory in all cases because some of the plants had been injured by low temperatures and, at that time, it was not always possible to distinguish between slight infection with bacterial wilt and winter injury. The plants were accordingly classified as infected, apparently not infected, and doubtful.

During the following winter, additional losses in stand occurred but no wilted plants were observed until near mid-summer. The percentage of dead plants in the spring and of wilt-infected plants on July 11 was estimated, the latter being based on the appearance of the top growth. A further reduction in stand was observed in the spring of 1928, and on April 19 the percentage of dead plants was determined. Some wilt was observed during the following summer, but no determinations of relative infection were made. The stand had become so thin on most of the plats that it was deemed advisable to discontinue the experiment. Table 1 gives the name and accession record numbers for the different varieties, the percentage of dead plants in the spring of 1926, 1927, and 1928, the percentage of wilt-infected plants as determined in 1926 and 1927, and the number of living plants per acre which still remained in the fall of 1928. It will be noted that there is a marked difference in the mortality of the different varieties, whether judged by the percentage of dead and wilt-infected plants, as recorded at various times, or by the final stand as given in the last column of the table. Thus, in November, 1928, Provence had a stand of 105,000 plants per acre (about 2.5 plants per square foot); Ladak, 75,000; and Turkestan, 71,000. In each case, the stands while thin were such that fair yields of hay would be secured under practical farm conditions. On the other hand, such varieties and strains as Grimm, Cossack, Dakota Common, Dakota No. 12, Utah, Kansas Common 435, and Sunflower, which are considered among those adapted to the central Great Plains, had stands of 45,000 plants per acre or less and were too poor to justify leaving for a hay crop had they been grown under farm conditions. Incidentally, from 14 to 48.7% of the 1928 crop of the latter group of plats was grass, the amount varying with the variety, whereas the highest percentage of grass in the three varieties first mentioned was 8.7%.

The differences in stand also correlate very well with the wilt infection and dead plants recorded at various times during 1926, 1927, and 1928. Thus, the highest percentage of wilted plants observed at any one time in Provence was 3.5 and of dead plants, 7.8; in Turkestan, 3.9 and 7.0; and in Ladak, 9.2 and 14.3. On the other hand, 32.5% of the Grimm plants were infected with wilt in July, 1927, and in April, 1928, 39.1% of the plants were dead. In July, 1927, 22.5% of the Kansas Common 435 plants were infected, and in the following spring 46% were dead.

TABLE 1.—*Living and dead plants and wilt-infected plants in alfalfa varieties and strains.*

Name	F. C. I. Acc. Rec. No.	Dead plants, April, 1926	Wilt-infected plants, May, 1926	Dead plants, April, 1927	Wilt-infected plants, July, 1927	Dead plants, April, 1928	Living plants per acre, November, 1928 (000 omitted)
		%	%	%	%	%	
Turkestan	2230	5.7	3.9	2.5	1.5	7.0	71
Italian	2123	16.5	11.2	30.0	17.5	42.5	24
Spanish	7101	26.6	27.9	50.0	22.5	56.8	9
Provence	34886	1.9	3.5	0.0	0.5	7.8	105
Cape Lucern	48094	17.4	12.3	40.0	40.0	53.3	4
Ladak		8.0	9.2	2.5	0.5	14.3	75
Dakota Common	455	8.2	6.7	25.0	15.0	41.6	43
Grimm	444	19.5	4.8	30.0	32.5	39.1	31
Cossack	2204	12.1	13.1	12.5	7.5	32.7	45
Dakota No. 12		18.0	15.8	27.5	17.5	41.7	37
Argentine	2231	23.6	8.3	35.0	25.0	45.1	15
Utah Common	2234	22.0	10.3	20.0	17.5	41.1	19
Sunflower*		28.0	10.7	30.0	22.5	40.2	17
Kansas Common	435	16.9	8.5	20.0	22.5	46.0	19
Kansas Common	(Check)	10.1	8.2	11.3	6.6	26.7	60

*This is a commercial lot said to be Kansas Common.

The cause of death of those plants which died during the winter cannot of course be determined, but the obvious correlation between the percentage of dead plants and wilt infection, the mildness of the winters as determined by their effect on other perennials and winter annuals, and the fact that varieties noted for winter hardiness were among those which suffered the most, are all in accord with the supposition that loss in stand in most of the varieties was chiefly the result of bacterial wilt. It was observed previous to 1926 that considerable losses above what is normally expected had occurred in the Spanish and the Cape Lucern varieties which are not adapted to Kansas conditions and perhaps the above observation should not apply to them.

GRIMM VS. KANSAS COMMON IN EASTERN KANSAS

For several years there has been much interest in Kansas in the relative merits of Grimm and Kansas Common, and because of this fact, the two varieties have been extensively used in cooperative varietal trials with farmers and in varietal trials and soil treatment trials at the five southeastern Kansas experimental fields. In the latter case, one-half of each plat has been seeded to Grimm and the other half to Kansas Common. These plantings have afforded an unusual opportunity to study relative infection with bacterial wilt, and advantage has been taken of this opportunity whenever wilt has made its appearance in any of the fields. The cooperative tests with farmers have usually included other varieties as well, but such data as were obtained are not of sufficient importance to justify their inclusion in this discussion.

Table 2 gives the percentage of infected plants in Grimm and in Kansas Common for all cases where comparable data are available. Observations were made in various ways according to circumstances. Thus, the determinations on the N. E. Coffey farm in Franklin County and on the Fort Scott Experimental Field were by actual count, diagnosis being made by the appearance of the top growth. On the Moran Experimental Field in 1927, determinations were made by digging up and examining the roots. Other determinations consisted of estimates based on the appearance of the top growth of the plants.

It will be seen that the average infection for the Grimm is 18.3% as compared with 4.6% for the Kansas Common. Also, in 27 of the 35 cases, the infection is greater in Grimm than in Kansas Common and in no case was it greater in Kansas Common than in Grimm. The data would appear to afford convincing evidence of a material difference in wilt infection between these two varieties.

The differences in infection in the soil treatment plats suggest a positive correlation between wilt infection and the application of certain fertilizers. However, the data are not consistent and since the subject is foreign to the purpose of this paper, a consideration of such relations is reserved for the future.

In the absence of inoculation experiments under controlled conditions, it is not possible to say whether the observed differences in wilt infection with different varieties are inherited or merely accidental. The observed differences, however, are too large and too consistent to be explained by what are ordinarily thought of as chance errors. If these characteristics are not inherited as such, it seems reasonable to believe that they are at least associated with differences

TABLE 2.—*Relative infection with bacterial wilt of Grimm and Kansas Common in eastern Kansas experimental trials.*

Location and description of test and date of observation	Plants infected Grimm	Kansas Common
	%	%
County Poor Farm, Atchison County, October, 1927	4.0	1.5
N. E. Coffey, Franklin County, October, 1927	19.0	10.2
Ft. Scott Experimental Field, October, 1927:		
Plat 1, lime and superphosphate	23.0	4.0
Plat 2, lime	37.0	17.0
Plat 3, lime, potassium, and phosphorus	23.0	19.0
Plat 4, lime and manure	29.0	13.0
Plat 5, lime	44.0	8.0
Plat 6, lime, manure, and superphosphate	51.0	16.0
Plat 7, lime, manure, and rock phosphate	40.0	12.0
Plat 8, lime	31.0	16.0
Plat 9, manure	24.0	2.0
Plat 10, no treatment	9.0	1.0
Plat 11, lime	3.0	2.0
Moran Experimental Field, October, 1927	45.0	18.0
Columbus Experimental Field, October, 1927	0.1	0.0
Lawrence Blythe, Morris County, May, 1929	0.1	0.1
Rest Experimental Field, May, 1929	7.5	0.0
Parsons Experimental Field, May, 1929:		
Plat 1, lime and superphosphate	95.0	0.0
Other plats	0.0	0.0
Columbus Experimental Field, May, 1929:		
Plat 2, lime and superphosphate	1.0	0.0
Plat 4, lime and rock phosphate	5.0	0.0
Other plats	0.0	0.0
Moran Experimental Field, May, 1929:		
Varietal test plats	0.1	0.0
Soil treatment plats:		
Plat 1, lime and superphosphate	5.0	0.1
Plat 2, lime	5.0	0.1
Plat 3, lime, potassium, and superphosphate	0.1	0.1
Plat 4, lime and manure	0.0	0.0
Plat 5, lime	1.0	0.0
Plat 6, lime, manure, and superphosphate	0.1	0.0
Plat 7, lime, manure, and rock phosphate	20.0	0.0
Plat 8, lime	20.0	1.0
Plat 9, manure	25.0	1.0
Plat 10, no treatment	15.0	0.0
Plat 11, lime	50.0	10.0
G. W. Goddard, Johnson County, May, 1929	10.0	10.0
Average	18.3	4.6

in growth habit or other characteristics which are inherited. Thus, it was observed that the three varieties found to be least affected have a characteristic decumbent or prostrate habit of fall growth. This may account for their resistance, since, as Jones (3) has pointed out, infection appears to be highly correlated with fall growth. This does not, however, entirely explain the difference between Kansas Common and Grimm since the latter is usually more decumbent in the fall in Kansas than is Kansas Common. However, it is not as decumbent as the Turkestan, Ladak, and Provence used in this experiment, nor is the decumbent characteristic as marked under Kansas conditions as it is farther north.

The apparent susceptibility of Grimm as compared with Kansas Common is not entirely in accord with the fact pointed out by Jones (3) and by Jones and Weimer (4) that infection seems to be associated with some mode of injury to the plant including winter injury, unless at the same time it be assumed that Kansas Common possesses some degree of resistance to bacterial invasion not possessed by the Grimm. Otherwise, Grimm would be expected to be more resistant than Kansas Common since it is the more winter hardy.

There are, of course, other possible explanations. One of these is the possibility that Grimm is more easily injured than Kansas Common when frozen in an unhardened condition, although more winter hardy under natural conditions and more hardy when frozen in a hardened condition as has been found by Hill and Salmon (1) to be the case for certain varieties of winter wheat

Steinmetz (6) has subjected Grimm and Kansas Common to low temperatures under controlled conditions and found that the Grimm was the more resistant in all cases. Most of the tests were made with hardened plants.

Weimer (7) has recently reported the results of freezing Grimm and Kansas Common under controlled conditions at Madison, Wisconsin. No differences in injury were recorded. In another case, plants of several varieties, including Grimm and Kansas Common, were collected from the field at various times from January 31 to August 28, 1928, at Manhattan, Kansas, and examined for ray splitting and for evidence of healing. There was no practical difference in the injury to the two varieties, but the Kansas Common seemed to heal more rapidly. However, not many plants were examined and the results are not entirely consistent.

It seems worthwhile in this connection to report some results recently secured at Manhattan, Kansas, in which certain of the varieties under discussion were subjected to artificial freezing as described for wheat by Hill and Salmon (1). Three separate experiments, each comprising a number of different comparisons, have been made.

In the first of these experiments, about 15 12-inch pots were seeded in the spring of 1928 to each of five varieties, *viz.*, Grimm, Provence, Cossack, Ladak, and Kansas Common. They were grown in the greenhouse until the winter of 1928–29 and were then subjected for 12 hours to temperatures between —9° and —11° C. After the plants had had an opportunity to recover, the injury was estimated. The average percentage for each variety was as follows: Provence, 44.3; Ladak, 70; Grimm, 74.4; Cossack, 78.2; and Kansas Common, 94.7.

In the spring of 1929, plants of different varieties were dug up from field plats at five different times, transplanted to 4-inch clay pots, and soon afterwards (usually the same day) transferred to the refrigerator where they were frozen at temperatures ranging, for various lots, from —15° to —26°C. The varieties included were Grimm, Ladak, Provence, and two lots of Kansas Common, one being of one-year-old plants and the other of two-year-old plants. All except the one lot of Kansas Common were from one-year-old plants seeded the preceding spring. The two lots of Kansas Common were included to show the effect of low temperature on different size plants since the Provence plants, because of a thin stand, were somewhat larger than the others.

This difference in size of these two lots, it may be noted, was considerably more than the difference between any two varieties. The plants for the first lot were dug on March 2 and for the fifth lot on March 14. Some frost was in the ground on nearly every date on which plants were taken, however the plants had begun to grow slightly. On March 27, an additional lot of 10 plants of each variety was removed from the soil and transplanted to 10-inch pots and frozen. With the exception of this last lot, each freezing lot contained 15 pots or 15 plants of each variety. The results of this experiment are presented in Table 3.

TABLE 3.—*Resistance of alfalfa varieties to artificially produced low temperatures, 1929.*

Date	Hours frozen	Minimum temperature, °C	Estimated injury				
			Provence	Grimm	Ladak	Kansas Common, 1 year old	Kansas Common, 2 years old
			%	%	%	%	%
March 2	12	—25.0	46.7	79.0		100	80
March 6	24	—26.1	80.0	86.7	100	100	86.7
March 7	24	—25.5	53.3	73.3	100	86.7	80.0
March 8	24	—23.9	66.7	33.3	6.7	73.3	20.0
March 9	24	—23.9	20.0	13.3	26.7	13.3	20.0
March 10	18	—21.1	13.3	26.7	33.3	26.7	0.0
March 11	18	—17.7	0.0	0.0	40.0	20.0	6.7
March 14	12	—15.0	13.3	6.7	6.7	20.0	46.7
March 14	12	—15.0	0.0	6.7	20.0	26.7	46.7
March 27			70.0	90.0	82.5	85.0	99.0
Average			36.3	41.6		55.2	48.6
Average, excluding the test of March 2			35.2	37.4	46.2	50.2	45.1

It will be noted that Provence killed the least of any, followed closely by Grimm, Ladak, and Kansas Common. The two-year-old Kansas Common plants killed slightly less than the one-year-old plants, but the difference, it appears, is not sufficient to permit explaining the greater resistance of Provence. In this test, it is quite evident that the Provence was best able to survive low temperatures, Kansas Common the least, and the others intermediate in the order named.

In the fall of 1929, field-grown plants, seeded the preceding August, of five varieties or regional strains, namely, Grimm, Provence, Ladak, Kansas Common, and Utah Common, were transplanted to 4-inch pots and frozen as in the preceding experiment. There were 15 plants in each lot. Seven lots in all were frozen between November 1 and December 6. Considerable cold weather with temperatures below 0° F occurred late in November, but the first three lots were frozen in an unhardened condition. The percentage of plants which were killed is shown in Table 4.

TABLE 4.—*Resistance of alfalfa varieties to low temperatures, 1929.*

Date	Minimum temperatures °C	Plants killed				
		Provence	Grimm	Ladak	Kansas Common	Utah Common
		%	%	%	%	%
November 1	—11	47.1	80.1	81.4	97.9	97.3
November 7	—11	30.6	97.1	55.0	94.3	99.2
November 9	—11	24.6	82.0	66.6	96.5	98.1
December 5	—21	38.2	83.2	68.3	99.0	98.8
December 5	—21	9.6	29.7	16.4	87.1	86.6
December 6	—17	75.9	78.3	46.7	100.0	95.1
December 6	—17	33.3	61.8	25.8	87.1	92.8
Average		37.0	73.2	51.5	94.5	95.4

Here also, it will be noted that Provence survived the best of all varieties with Ladak second, Grimm third, and Kansas Common and Utah Common about equal. With the exception of Grimm and Ladak, which have changed places, the rank is the same as in the preceding test.

The data presented perhaps do not afford much additional evidence as to the cause of the difference in infection by bacterial wilt previously discussed. They do indicate, however, that Provence is decidedly more resistant to low temperatures than the other varieties and that Ladak also is highly resistant as compared with the Kansas Common. So far as these varieties are concerned, therefore, the difference in wilt infection might be explained by their greater resistance to low temperature. This explanation, however, does not hold for Grimm, since it also is more hardy than the Kansas Common, nor do the data support the assumption that susceptibility is related to a lack of resistance to low temperature when frozen in an unhardened condition.

In view of the outstanding record for Provence, Turkestan, Ladak, and possibly one strain of Kansas Common, it appears that some comments regarding the origin and possible value of these varieties are in order. The Provence is a strain secured by the Office of Forage Crop Investigations, United States Department of Agriculture, from Provence, France. Its habits of growth and behavior in field tests, however, are quite different from other lots imported under the same name. A number have been included in various tests since 1922 and all of them have been decidedly unsatisfactory, either because of lack of winterhardiness or for other reasons. The particular strain included here appears not only to be highly resistant to wilt and to low temperatures, but also seems to have the ability to produce satisfactory yields of hay. But very few tests have been conducted because of lack of seed. Steps have been taken to remedy this defect.

The Ladak variety has been described by Westover (8) and is considered promising for northern states. In Kansas, it makes a slow growth during the summer and yields are consequently low.

The Kansas Common used in the check plats at Manhattan was secured from W. J. Sayre who had raised it in Chase County, Kansas, for a number of years. It seems to be superior to other strains of Kansas Common only with respect to resistance to wilt. The Kansas Common included in the tests in eastern Kansas was not the same as that included in the plats at Manhattan. As a matter of fact, the origin of seed used in the former tests has varied from year to year, the only point in common being that each lot is known to have been grown in Kansas for a number of years.

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NITROGEN AVAILABILITY IN "BASED" AND UNBASED AMMONIUM SULFATE AND AMMONIUM PHOSPHATE[1]

A. B. Beaumont and T. R. Swanback[2]

It is a more or less common practice among fertilizer manufacturers to mix fresh superphosphate with ammonium sulfate and let the mixture cure in storage. Some heat is generated by the mixing and the mass later sets or hardens during the curing process. The cured mixture is reground before mixing with other ingredients to make a finished complete fertilizer. This method of handling ammonium sulfate and superphosphate is known in the trade as "basing" and the product as "based" ammonium sulfate.

The generation of heat during "basing" is taken by some as evidence of a chemical reaction, and it is assumed that the following metathetical reaction occurs (stated simply): $(NH_4)_2SO_4 + CaH_4(PO_4)_2 = 2\ NH_4H_2PO_4 + CaSO_4$.

The reaction no doubt occurs to a limited extent, but how far it goes under the conditions of the factory has not been determined. It is of the reversible type and therefore cannot be expected to go to completion in the fertilizer mixture.

The fertilizer manufacturer has found the "basing" process to be good factory practice and it has been thought that a superior form of plant food is formed in the process; the latter on account of the assumed presence of ammonium phosphate. A number of experiments have been reported which show that ammonium phosphate is a satisfactory carrier of nutrient nitrogen and phosphorus, if used under certain optimum soil conditions. Unfortunately, the soil conditions existing in many of the experiments have not been determined or reported. Some have assumed that ammonium phosphate is superior to ammonium sulfate under strongly acid soil conditions, but that there is no advantage for ammonium phosphate under slightly acid or neutral conditions.

Theoretically, the ultimate effect on the soil of "based" ammonium sulfate as compared with unmixed ammonium sulfate plus superphosphate should be the same, regardless of chemical changes that may occur in the "basing" process; for the chemical reaction is undoubtedly a reversible one, and when the "based" mixture is added to the soil the presence of moisture would tend to induce the same equilibrium that existed before "basing" occurred.

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The purpose of the present investigation was to determine the relative growth response of a series of crop plants to "based" and unbased ammonium sulfate applied to soils of different degrees of acidity.

METHODS AND PROCEDURE

Plants were grown in paraffined zinc Wagner pots of 3 gallons capacity. Treatments were replicated 5 and 10 times; 5 times when several plants were grown, and 10 times when only one plant was grown in each pot. The moisture content of the soils was maintained at 50 to 60% maximum moisture retentive capacity.

The surface soil was obtained from the unlimed and limed halves of unfertilized plats which had received no fertilizer within 36 years, *viz.*, plats 4, 8, and 12 of the North soil test. The limed half of the plats received a total of 4½ tons of lime per acre in 36 years. The subsoil came from a sandpit known to contain sand deficient in nitrogen and phosphorus. The chemical and physical characteristics of the soils are given in Tables 1 and 2.

TABLE 1.—*Some chemical characteristics of the soils used.**

Soil	Treatment	pH value	Lime requirement† (pounds CaO)	Organic and volatile matter %
Surface soil	Unlimed	4.8	5,368	3.46
Surface soil	Limed	5.8	1,902	3.97
Subsoil	Untreated	6.4	441	0.70

*Analytical work by Fertilizer Control Laboratory.

†By Jones calcium acetate method.

TABLE 2.—*Mechanical analysis of soils (unlimed) used.*

Separates	Surface soil %	Subsoil %
Fine gravel (2.0–1.0 mm)	0.80	0.93
Coarse sand (1.0–0.5 mm)	1.36	2.44
Medium sand (0.5–0.25 mm)	2.02	9.05
Fine sand (0.25–0.10 mm)	9.43	60.55
Very fine sand (0.10–0.05 mm)	36.47	22.74
Silt (0.05–0.005 mm)	44.28	3.34
Clay (0.005 mm–)*	5.64	0.95

*By difference.

Table 3 gives the analysis of the fertilizer materials used, which were kindly furnished from stock supplies by a fertilizer manufacturer. In addition, chemically pure primary ammonium phosphate, ammonium carbonate, and calcium sulfate were used. Fertilizer treatments are given in Table 4.

Fertilizer was applied to all soils for corn, to the surface soil at the rate of 1,000 pounds per acre, and to the subsoil at the rate of 2,000 pounds per acre. The application to the subsoil was repeated for lettuce.

TABLE 3.—*Chemical composition of fertilizers used.**

Composition	Material Superphosphate	 Ammonium sulfate	 "Based" goods	 Muriate of potash
	%	%	%	%
Moisture	5.89	0.17	9.30	0.21
Total phosphoric acid (P_2O_5)	15.15	—	14.48	—
Soluble phosphoric acid(P_2O_5)	13.65	—	13.04	—
Reverted phosphoric acid (P_2O_5)	0.29	—	1.44	—
Insoluble phosphoric acid (P_2O_5)	1.21	—	0.00	—
Total nitrogen (N)	—	20.84	—	—
Total potassium oxide (K_2O)	—	—	3.63	50.88

*Analytical work by Fertilizer Control Laboratory.

TABLE 4.—*Fertilizer and chemical treatments given soils.*

Treatment A

Sulfate of ammonia Superphosphate Muriate of potash	In proportions to approximate a mixed fertilizer containing 3% NH_3; 12% available P_2O_5; and 4% K_2O.

These materials were added to the surface of the soil separately and stirred in separately, to avoid any undue amount of chemical reaction before mixing with the soil.

Treatment B

"Based" mixture and muriate of potash, furnishing plant nutrients equivalent to those in A.

Treatment C

Ammonium phosphate
Muriate of potash

In addition, a small amount of ammonium carbonate to make the total contain the same ratio of nutrients as in A and B.

Treatment D

Same as C plus calcium sulfate equivalent to that carried by the superphosphate used in A and B.

No fertilizer was applied for the oats and barley, but for turnips and beets the original treatment was repeated. Only one application of lime was made and that to the subsoil at the rate of 735 pounds of agricultural lime (60% CaO) to the acre, which was theoretically sufficient to neutralize the soil.

The following crops were grown in succession: (a) Sweet corn, planted March 30, 1926, harvested June 12, 1926. Ten pots of each treatment; one plant to a pot. (b) Cos (Romaine) lettuce, sown July 31, 1926, harvested October 23 and November 1, 1926. Ten pots of each treatment; three plants to a pot. (c) Oats and barley, seeded November 13, 1926, harvested February 23, 1927. Five pots of each treatment instead of 10 as before. Treatment C dropped from the experiment before oats and barley were seeded. (d) Turnips and beets, seeded about March 15, harvested May 23, 1927. Only treatments A and B used.

RESULTS

The yield data are given in Tables 5 and 6.

TABLE 5.—*Yields of crops grown on surface soils in grams of air-dry material.*

	Unbased ammonium sulfate (A)		Based ammonium sulfate (B)		Ammonium phosphate (C)		Ammonium phosphate + calcium sulfate (D)	
Crop	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed
Corn*	18.75	10.99	12.75	6.49	18.35	4.75	18.71	7.39
Lettuce†	5.69	0.49	5.54	0.46	6.43	0.61	8.59	0.72
Barley‡	2.86	0.62	3.68	0.36			3.96	0.86
Oats‡	5.78	2.22	7.20	3.92			7.52	4.66
Turnips§	16.06	——	21.04	——				
Beets§	6.65	——	6.62	——				
Totals	55.79	14.32	56.83	11.23				

*Average yield from 10 pots, 1 plant to a pot.
†Average yield from 10 pots, 3 plants to a pot.
‡Average yield from 5 pots, 10 plants to a pot.
§Average yield from 5 pots.

TABLE 6.—*Yield of crops grown on subsoil sand in grams of air-dry material.*

	Unbased ammonium sulfate (A)		Based ammonium sulfate (B)		Ammonium phosphate (C)		Ammonium phosphate + calcium sulfate (D)	
Crop	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed
Corn*	14.12	13.16	16.26	13.35	14.22	13.67	15.93	14.57
Lettuce	4.64	1.52	3.38	1.22	——	——	——	——
Barley	2.50	1.88	2.02	0.92	——	——	——	——
Oats	2.88	3.96	3.26	3.50	——	——	——	——
Totals	24.14	20.52	24.92	18.99				

*Same number of pots and plants as in Table 5.

DISCUSSION OF RESULTS

A study of the yield data brings out the following relationships.

1. DIFFERENCES DUE TO SOIL TYPE AND LIME

The limed surface soil produced larger crops than the limed subsoil, although much more fertilizer was applied to the subsoil. On the other hand, the growth on the unlimed subsoil was superior to that on the unlimed surface soil. In other words, there was a greater difference in growth on the limed and unlimed surface soil than on similarly treated subsoil.

2. DIFFERENCES DUE TO CROP

Barley, lettuce, turnips, and beets were very sensitive to acid soil conditions. All these crop plants, except turnips, are commonly considered as strongly acid-sensitive. Corn and oats were less sensitive than the other crops. The difference between barley and oats with respect to sensitiveness to soil acidity was especially marked. In fact, the growth of oats was slightly better on the unlimed than on the limed subsoil.

3. DIFFERENCES DUE TO FERTILIZER

On limed surface soil, the number of crops with which based or unbased ammonium sulfate had an advantage in yield was evenly divided. Also, the total yields of all crops from the two sources of nitrogen were so nearly the same (55.79 vs. 56.83 grams) that difference is considered as not statistically significant. A very similar numerical relation exists between the yields from the two sources on the subsoil sand.

On unlimed surface soil, the unbased ammonium sulfate was superior to the based material with three out of four crops. The total yield of four crops grown with the unbased material exceeded that from the based goods by 27.5%. This difference is thought to be statistically significant, although the data do not lend themselves to statistical interpretation.

On the less acid but unlimed subsoil sand, the difference between the yields from the two sources of nitrogen is in the same direction as with the unlimed surface soil, but the difference is so small that it is not considered statistically significant. On the limed subsoil, there was a very small but insignificant difference in favor of the based material.

As for ammonium phosphate, either alone or with $CaSO_4$, there are insufficient data for a fair comparison with based or unbased ammonium sulfate. It may be noted, however, that ammonium phosphate behaves very similarly to ammonium sulfate in relation to plant growth. The use of $CaSO_4$ with ammonium phosphate was beneficial.

SOIL CONDITIONS AND PLANT GROWTH

Although not coming directly within the scope of the original objective of the investigation, immediately after the harvest of the corn crop studies were begun to see if soil conditions which caused the marked difference in growth could be determined. It was suspected, among other factors, that soluble alumina which might accompany a high degree of acidity caused the poor growth on the unlimed soil. Accordingly, determinations were made of alumina of the soil soluble in 0.5 N acetic acid, and of total alumina and certain other constituents in the stalks.

From Tables 7 and 8, it is apparent that there were no significant or consistent differences in the alumina content of the limed and unlimed soils or in the crops grown on them. In both soils and both treatments the soluble alumina was below what might be expected to be toxic to corn according to the work of Hartwell (3).[3] As might have been expected, the percentages of calcium, magnesium, and phosphorus were much higher in the stalks grown on limed than those grown on unlimed surface soil.

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[3] Reference by number is to "Literature Cited," p. 818.

TABLE 7.—*Alumina soluble in 0.5 N acetic acid in soil samples drawn after the corn crop was harvested.**

Soil	Treatment	Al in p.p.m.
Surface	Limed, "based" ammonium sulfate	404
Surface	Unlimed, "based" ammonium sulfate	410
Subsoil	Limed, "based" ammonium sulfate	268
Subsoil	Unlimed, "based" ammonium sulfate	220

*Analytical work by the Fertilizer Control Laboratory.

TABLE 8.—*Chemical constituents in corn stalks (without leaves).**

Soil and treatment	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	Sand and soluble SiO_2 %	K_2O %	P_2O_5 %
Surface, unlimed: A	0.0232	0.0308	0.239	0.145	0.633	2.79	0.217
B	0.0577	0.0123	0.284	0.145	0.740	3.27	0.255
C	0.0544	0.0246	0.206	0.159	0.670	2.64	0.128
D	0.0369	0.0431	0.280	0.149	0.655	2.97	0.204
Surface, limed: A	0.0325	0.0215	0.321	0.283	0.408	2.72	0.440
B	0.0554	0.1046	0.375	0.388	0.492	4.02	0.555
C	0.0392	0.0308	0.284	0.261	0.442	2.49	0.370
D	0.0322	0.0338	0.292	0.228	0.411	2.30	0.332
Subsoil, unlimed: A	0.0335	0.0215	0.194	0.232	0.803	1.60	0.717
B	0.0327	0.0123	0.148	0.185	0.708	1.82	0.625
C	0.0246	0.0154	0.152	0.228	0.740	1.73	0.800
D	0.0296	0.0154	0.185	0.252	0.793	1.58	0.756
Subsoil, limed: A	0.0258	0.0092	0.185	0.225	0.688	1.64	0.727
B	0.0365	0.0185	0.177	0.214	0.655	1.51	0.590
C	0.0315	0.0185	0.173	0.246	0.623	1.54	0.800
D	0.0246	0.0154	0.227	0.272	0.633	1.60	0.880

*Analytical work by Fertilizer Control Laboratory.

Corn stalks were examined qualitatively for soluble alumina and iron according to the method of Hoffer (4). Although the results were not clearly defined, it appeared that positive tests for alumina were obtained with the stalks grown on the unlimed surface soil with all treatments. Positive tests were not obtained with the limed surface soil or limed or unlimed subsoil. Stalks from only one soil treatment, the limed surface soil treated with "based" ammonium sulfate, gave a pronounced iron test; other samples gave very irregular and indefinite iron tests.

The soil reaction was determined after the harvest of each crop, and the data are summarized in Table 9. It may be noted that both limed and unlimed subsoil became progressively more acid, and the unlimed surface soil slightly more acid as the investigation continued. The limed surface soil was not permanently affected, if at all. The data indicate a stronger buffer capacity of the surface soil, especially the limed portion, than of the subsoil. This characteristic is expected in a soil well supplied with lime, organic matter, and colloidal mineral material.

It was also suspected that possibly the small amount of ammonium carbonate added to treatments C and D might have exerted some toxic action on the plants. Accordingly, a minor test of ammonium carbonate, in comparison with other nitrogen carriers, was made on unlimed surface soil. The results are given in Table 10. It appears from this test that ammonium carbonate was at least no more toxic to corn as used than were ammonium sulfate and ammonium phosphate.

TABLE 9. *Soil reaction at various stages of the experiment expressed as pH values.**

Soil and treatment	Before cropping (untreated)	After 1st crop	After 2nd crop	After 3rd crop	After 4th crop
Limed surface	5.8			—	—
A	—	5.8	5.0	6.0	5.9
B	—	5.9	5.0	6.0	5.9
Unlimed surface	4.8	—	—	—	—
A	—	4.8	4.6	4.8	4.4
B	—	4.7	4.7	4.8	4.4
Limed subsoil			—	—	—
A		6.1	5.0	5.4	5.4
B	—	6.1	5.1	5.4	5.4
Unlimed subsoil	6.4	—	—	—	—
A	—	5.6	4.7	5.0	5.1
B		5.6	4.7	5.0	5.1

*With the exception of data for untreated soils and after the 4th crop, which were obtained with the potentiometer, pH determinations were made colorimetrically. Colorimetric data on soils containing considerable fine material are subject to greater error than those on the coarser soils.

TABLE 10.—*Yield and soil reaction in first minor test with corn.*

Nitrogen carrier	Dry weight in grams	pH
Ammonium phosphate	12.7	4.3
Ammonium carbonate	14.6	4.7
Ammonium sulfate	8.0	4.4
Sodium nitrate	20.2	4.7

After the harvest of the lettuce crop, it was suggested that possibly a deficiency of nutrient calcium was the cause of the very poor growth on unlimed surface soil. Accordingly, five of the unlimed surface soils previously treated with ammonium phosphate were treated with calcium sulfate at the rate of 1 ton per acre and five others were treated with an amount of sodium carbonate which would theoretically neutralize the acidity of the soil, and these were compared with five pots of limed soil. Lettuce was seeded, but growth of any consequence was obtained on the limed soil only. It seems from this minor test that the poor growth on the unlimed surface soil could not have been due to a deficiency of nutrient calcium.

After the poor results with beets and turnips on unlimed surface soil and both unlimed and limed subsoil, soluble salts were determined and a test made for water-soluble zinc. No trace of zinc was found in the water extract, and no consistently high concentration of soluble salts was found.

Although we have no satisfactory explanation of the soil conditions which caused the poor growth of beets and turnips, it appears that the high degree of acidity induced in unlimed surface soil and possibly in unlimed sand was the major factor responsible for poor growth on these soils. This investigation, in common with others (1, 2, 6), has shown that both ammonium sulfate and ammonium phosphate induce or tend to induce soil acidity, and that "based" ammonium sulfate acts similarly.

Since the completion of the vegetative experiments described in this paper, Jones (5) has proved that certain soils of the vicinity from which those used in the experiments came are deficient in available magnesium. In the light of this information and the data on magnesia content of the corn stalks as given in Table 8, it is now suspected that the unlimed soils were deficient in magnesium. It is planned to investigate this point later.

SUMMARY AND CONCLUSION

Crop responses to "based" and unbased ammonium sulfate and ammonium phosphate were measured by means of vegetative pot tests. Six crop plants were grown on two soils, each with two degrees of acidity. Under the conditions prevailing in the investigation, "based" ammonium sulfate produced no greater growth of plants than did the unbased and unmixed materials. Further, ammonium phosphate was not superior to either of the forms of sulfate on acid soils supplied with phosphoric acid equivalent to that in the ammonium phosphate. All ammonium salts used tended about equally to produce or intensify acid soil conditions. The soil acidity itself rather than associated indirect effects was the primary cause of the toxic soil condition which existed in some cases.

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NOTE

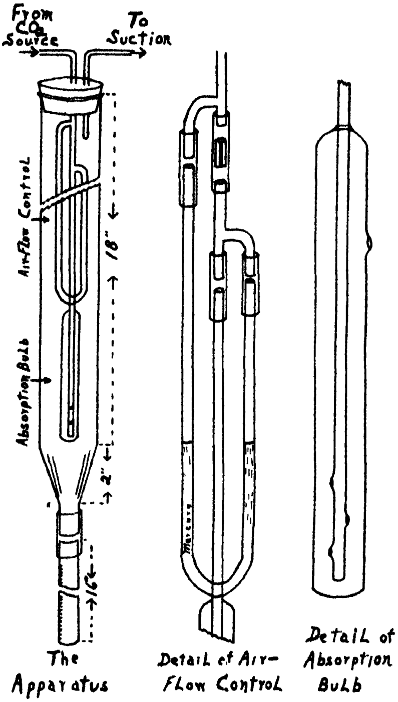
A METHOD FOR MEASURING TIME-RATE CARBON DIOXIDE PRODUCTION

The usual method of determining the rate and amount of CO_2 produced under varying conditions is to absorb the gas in an alkali solution and titrate. The alkalies generally employed are the hydroxides of Na, K, or Ba. It is generally conceded that the latter is the most efficient absorbent, but, due to its great affinity for atmospheric CO_2, is difficult to manipulate. $Ba(OH)_2$, however, differs from the other alkalies in the fact that the carbonate is insoluble, hence settles out as a white flocculent precipitate. This fact suggested the possibility that the volume of precipitant might be taken as a measure of the rate and amount of CO_2 production. Preliminary experiments indicate the feasibility of more or less accurately measuring the amount of CO_2 being produced from a given source without titration, also that a continuous record of the time-rate of production may be secured.

The apparatus employed differs from the usual absorption tower only in the fact that it is of much greater height and is equipped with an automatic air control. The apparatus and important details are illustrated in Fig. 1. The large absorption tube is approximately 21 inches long. The lower end is gradually tapered to a diameter of ½ inch. Provision is made for a nipple to which is attached a tube ½ x 16 inches. This smaller tube will hold approximately 45 cc. The arrangement is such that the liquid in the upper portion of the tube is continually disturbed by the passage of air bubbles from which the CO_2 is absorbed. A certain amount of $BaCO_3$ will remain in suspension, but the larger crystals will tend to grow to such a size that they will settle out. They settle into the undisturbed liquid in the tube below where the amount of floc may be readily measured on the graduated scale. The usual guards are employed to prevent contamination of the CO_2 source with atmospheric CO_2, also to prevent back suction, but are not illustrated. It will be noted that the number of external, or exposed, connections are reduced to a minimum, thus tending to reduce dangers from leaks.

The amount of vacuum in each tube is automatically regulated by the air-flow control apparatus shown in the figure. This consists of two U tubes connected in such a manner that the air is forced to flow directly through one arm. Interposed between the connection is a short piece of thermometer tubing. The restricted opening of the latter regulates the amount of air flow. The vacuum in the various tubes is equalized by closing the free ends of the U tubes with a long U tube containing approximately 2 inches of mercury.

The absorption bulb shown in detail in Fig. 1 is made of 6-cm tubing pierced with a number of small holes. The holes are made with a hot platinum wire. The bottom of the tube is left open. The tube is sealed in a 15 by 150 cm test tube in the side of which a hole (3 to 4 cm) is blown about 2 inches below the seal. This modification of the "Folin absorption tube" provides for trapping the CO_2-laden air for a short time, thus giving maximum absorption and at the same time allowing the $BaCO_3$ that is continually forming to settle freely.



The Apparatus

Detail of Air-Flow Control

Detail of Absorption Bulb

Fig. 1.

At present the indications are that the method will not supplant the usual titration method, in fact, if accurate results are desired, the solution should be titrated in the usual manner. It does, however, offer the advantages of a controlled air flow with a minimum number of connections and the measurement of the time-rate of CO_2 production without disconnecting. It is hoped that it will have an application in the field of respiration studies.—PAUL EMERSON, *Department of Farm Crops and Soils, Iowa State College, Ames, Iowa.*

BOOK REVIEWS

BACTERIOLOGY, A TEXT BOOK ON FUNDAMENTALS

By Stanley Thomas. New York: McGraw Hill Book Co., Ed. 2, XV +301 pages, illus. 1930.

A textbook in elementary bacteriology designed to meet the "need of a text which treats of the fundamentals *** upon which the chemist, the medical student and the sanitary engineer can build a superstructure of his own specialized knowledge."

The first chapter is a review of material generally covered in courses in general biology, *viz.*, life, composition of living matter, the cell, evidences of life, reproduction, species variation, and the relation of living things to each other. The student is introduced to bacteriology in chapter 2 on the history of bacteriology. The author gives an interesting development of bacteriology, which should serve to arouse the student's interest.

In chapter 3, sixteen pages are devoted to the classification of bacteria. This is more than is generally accorded to the topic, but the reviewer believes the space is well used. Some teachers may prefer to take up the topic after a study of morphology and physiology has been concluded. The use of italics for scientific names would improve the text.

The discussion of growth curves of bacteria in chapter 6 is not entirely accurate. In discussing geometric increase in numbers of bacteria, the author states, "in other words, a curve representing the increase in numbers with time would be a straight line." This obviously would not be the case, but the curve would be a constantly ascending one; that is, since the increase is geometric it would always be proportional to the number of bacteria present at the beginning of the interval of time, therefore, the increase in numbers becomes greater with each interval of time. Plotting the logarithms of the number of bacteria against time will give a straight line. Figs. 14 and 15 are incorrect, the ordinates in both figures should read "logarithms of the numbers of bacteria."

Following the chapters on fundamentals there appear chapters treating of bacteria in the soil, in water, in sewage, in the air, and in food. These are followed by chapters on pathogenic bacteria, immunity, hygiene, and sanitation and bacteria in industry. In general, recent work in the science of bacteriology has been included. Possibly the space devoted to the theories of Ehrlich could be reduced and the work of Bordet and the "colloidal" aspect of immunity reactions given this space. The chapter dealing with bacteria in industry could be strengthened. The author has an interesting style and the treatment of subject matter is modern. In all, the book is a worthwhile text in elementary bacteriology.—(C. H. W.)

THE PRINCIPLES OF AGRONOMY

By Franklin S. Harris and George Stewart. New York: The Macmillan Co. 581 pages, illus. Revised Ed. 1930. $2.00.

This book is a revision of the 1915 edition of the same title and by the same authors. Like the first edition it is designed for use as a text in high schools giving considerable class work in agriculture; as well as a practical book for farmers. As the authors state in the preface, the past 15 years have produced many important changes in agronomy and in the teaching of this subject which have necessitated an almost complete rewriting of the older edition. With the new material incorporated, together with many new illustrations, this book contains over a 100 more pages than the older edition.

The very valuable feature of many appendix tables and a glossary of terms found in the first edition is retained and enlarged. By no means least in valuable features is a very complete index. The arrangement of material is almost identical with that in the original edition.

Part I of the book deals with the plant and its environment, structure, and functions; part II with the soil from the standpoints of origin, properties, water, nutrients, biology, and cropping; part III with farm crops, which includes some 35 pages on pastures and grasses; and part IV with farm management.

The material of the text is well arranged and clearly presented and should be as interesting and helpful to eastern and mid-western as to western farmers. The illustrations likewise are taken from a wide geographic range. This new edition should be welcomed by those institutions which have been using the older text in their teaching work.—(R. C. C.)

HANDBUCH DER BODENLEHRE (HANDBOOK OF SOIL SCIENCE) II. THE PROCESS OF WEATHERING AND ITS CLIMATOLOGICAL PRINCIPLES

E. Blanck, Editor. Berlin: J. Springer. VI + 314 pages, illus. $7.50 unbound; $8.00 bound. 1929.

The first 147 pages of this volume, so far as it is of interest to soil scientists, is devoted entirely to climatology. K. Knoch gives a condensed review of "climatic factors, and climatic zones on earth." I. Schubert's treatise on "the climate directly above the soil" which has a close bearing on plant and crop ecology will prove of great value to agronomists. About 50 pages are taken up by the much-disputed subject of climatic changes. This section will be appreciated by all those who are interested in buried soils, gumbo tills, and the origin of prairie soils. E. Wasmund reviews the voluminous literature and discusses objectively and critically the various methods and results of the investigations on "climatic changes during younger geological periods, including post glacial time;" while G. Schellenberg reviews the modern method of "pollen analyses" which has become one of the most valuable tools in the study of climatic changes and the determination of the age of humus deposits (peats).

The remainder of the book (150 pages) deals with weathering processes or, more accurately, with "influences and effects of physical, chemical, geological, biological, and other factors on the parent material." E. Blanck contributes two elaborate and carefully written chapters on physical and chemical weathering (62 pages) based mainly on German literature. About an equivalent amount of space is devoted to biological weathering which includes "decomposition of organic matter" (by K. Rehorst), "effects of lower and higher living plants" (by G. Schellenberg and E. Blanck), and an unusual, but very interesting chapter on "biological weathering as the result of decomposing organic substances" (by E. Blanck).

As a whole, this second volume is well written and contains much valuable information for both teachers and research workers in soil science.—(H. J.)

AGRONOMIC AFFAIRS

MEETING OF WESTERN SECTION OF SOCIETY

The fourteenth annual conference of the Western Section of the Society was held at Bozeman, Montana, from July 30 to August 1, 1930, The attendance by states was as follows: Montana, 13; Idaho, 7; Oregon, 4; Colorado, 4; North Dakota, 3; Utah, 2; South Dakota, 2; Washington, 1; New Mexico, 1; Wisconsin, 1; California, 1; Minnesota, 1; Alberta, Canada, 1; Nebraska, 1; and the U. S. Dept Agriculture, 6.

PROGRAM

July 30

1. Roll Call—answered by self introduction and brief resume of problems under investigation.
2. Address of Welcome, Dr. Alfred Atkinson, President, Montana State College.
3. Response, H. W. Hulbert, Head Department of Agronomy, Idaho Experiment Station.
4. Fertility of the Dry-Lands, A. F. Bracken, Supt., Nephi Branch Station, Utah.
5. Summer Tillage Investigations at North Montana Branch Experiment Station, by M. A. Bell, Asst. Superintendent.
6. Water Requirement Experiments at Moro, Oregon, D. E. Stephens, Supt., Sherman County Branch Station, Oregon.
7. A Cereal Variety Survey of Oregon, D. D. Hill, Associate Agronomist, and D. E. Stephens, Supt., Sherman Branch Station, Oregon.
8. Cereal Nursery Experiments in the Columbia Basin of Oregon, D. E. Stephens, Supt., Sherman Co. Branch Station, Oregon.
9. Comparative Yield of Proso, Corn, and Barley Grown Under Dry Land Conditions at Akron, Colorado, D. W. Robertson, Alvin Keyser, and J. F. Brandon, Colorado Experiment Station.
10. Bacterial Wilt of Alfalfa in Colorado, Alvin Kezer, Agronomist, Colorado Experiment Station.

11. Symposium on "The Present Status of Pasture Investigations".

A. Range Improvement Possibilities, M. A. Bell, North Montana Branch Station, Havre, Montana.

B. Dry Land Pasture Experiments, Harold Tower, Judith Basin Branch Station, Moccasin, Montana.

C. Irrigated Pastures, A. E. McClymonds, Supt., Aberdeen Branch Exp. Station, Aberdeen, Idaho.

D. Ladino Clover, E. R. Jackman, Extension Agronomist, Oregon State College.

July 31

12. Cereal Variety Tests, A. E. McClymonds, Supt., Aberdeen Substation, Aberdeen, Idaho.

13. The Inheritance of Dwarfs in Wheat, D. C. Tingey, Assistant Agronomist, Utah Experiment Station.

14. Inheritance Studies of Winter Hardiness and Winter-Spring Growth Habit in a Winter x Spring Wheat Cross, K. S. Quisenberry, Cereal Crops & Diseases, U. S. Dept. of Agriculture.

15. Inheritance of Smut Reaction, Awnedness, and Other Characters in Hope Wheat Crosses at Bozeman, Montana, J. A. Clark and K. S. Quisenberry, Cereal Crops and Diseases, U. S. Dept of Agriculture and LeRoy Powers, Montana Experiment Station.

16. The Relation of New Physiological Forms of Stem Rust of Wheat and the Production of Resistant Varieties, O. S. Aamodt, University of Alberta.

17. Some ways of Stepping up the Breeding Program, F. A. Coffman, Cereal Crops & Diseases, U. S. Dept. of Agriculture.

18. The Enlarged Wheat Breeding Program for the Western States, J. A. Clark, Cereal Crops & Diseases, U. S. Dept. of Agriculture.

19. Symposium on "Weed Control".

A. The Use of Chlorates in the Eradication of Perennial Weeds in Utah (Progress Report), D. C. Tingey, Assistant Agronomist, and Lionel Harris, Graduate Student, Utah Experiment Station.

B. Acidity a Factor in the Successful use of Chlorates as Weed Killers, H. W. Hulbert, University of Idaho.

C. Weed Experiments in Montana, A. H. Post, Acting Agronomist, Montana State College.

The annual banquet was held at the Baxter Hotel Thursday evening, July 31. Short talks were given by Director B. F. Linfield of the Montana Experiment Station, O. S. Aamodt of the University of Alberta, K. S. Quisenberry of the Office of Cereal Crops and Diseases, and George Stewart of the Utah Experiment Station. At the business meeting which followed the banquet Alvin Kezer, agronomist of the Colorado Experiment Station, was elected president and A. F. Bracken, Superintendent of the branch station at Nephi, Utah, Secretary. The conference voted to meet at Logan, Utah, in 1931. The experimental plats of the agronomy department of the Montana Experiment Station were visited during the morning of August 1. —B.B BAYLES, *Secretary*.

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NITROGEN AND ORGANIC MATTER AS RELATED TO SOIL PRODUCTIVITY[1]

W. L. POWERS AND R. D. LEWIS[2]

In an earlier report the value of fertilizer application for increasing the concentration of the soil solution and decreasing the water requirements of plants has been demonstrated. The present article is intended to indicate the possibilities for maintaining soil nitrogen and organic matter and consequently efficient use of water and profitable irrigation agriculture through such economic methods as crop rotation and the use of barnyard manure.

Bringing soils under cultivation causes a serious disturbance from the standpoint of the soil. Plants are usually removed instead of being allowed to decay where they grew, while temperature, moisture, and aeration relations are altered and micro-organic life is thrown out of balance. Under cultural conditions, decomposition of organic matter may exceed its formation.

Such disturbances greatly affect the organic matter supply of soils which has an important bearing on both the physical and chemical characteristics or response in crop yields. Organic matter influences structure, affects aeration, drainage, water-holding capacity, checks erosion, and causes more rapid warming up of soil in the spring. Organic matter may contribute to the supply of soil colloids and base adsorbing capacity or release acids which react to increase the concentration of some inorganic soil constituents in the soil solution. The number of micro-organisms and their activities may increase in the presence of an increased supply of organic residues. Organic matter has a buffer action in the soil which helps to regulate soil reaction. Upon mineralization it directly supplies nitrogen and mineral elements.

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[1] Contribution from the Soils Department, Oregon Agricultural Experiment Station, Corvallis, Ore. Published with the approval of the Director. Received for publication April 9, 1930.

[2] Soil Scientist and Research Fellow, respectively.

The practices that have been relied upon for the maintenance if not the increase of organic matter are the uses of crop residues, green manures, barnyard manures, and commercial fertilizers.

To bring cultivated regions which are lacking in rainfall suitable for maximum crop growth under irrigation seems to bring about favorable conditions in the soil from the standpoint of crop production. Yields are enlarged in striking contrast to the scattered vegetation which originally occupied the virgin land. Because of this increased production residues left in the soil may increase the organic matter, and this is the problem which will be given consideration.

HISTORICAL

It has long been recognized that constant cropping with grain in humid climates tends to diminish the amount of organic matter in the soil (4)[3] unless careful use is made of green manure crops or barnyard manure. The result is a change in the physical character of the soil, with reduced granulation, lowered water capacity, and lower soil temperatures under humid conditions.

Duplicate determinations made in 1905 by the senior author from samples taken from the Morrow plats at Illinois Agricultural Experiment Station gave loss on ignition as follows: (a) Soil from permanent sod area, 8.05%; (b) soil from an area cropped to corn 29 years, 5.8%.

The senior author also reported (5) "humus" (Matiere-Noire method) content in 1915 of (a) virgin black sage land and (b) adjacent old alfalfa meadow which had been reclaimed from sagebrush and in irrigated alfalfa for a decade or more. The soil was a light brown very fine sandy loam. Without irrigation the humus content was 0.36%. With irrigation of meadow land, the humus increased to 0.45%, representing a gain in soil organic matter under irrigation farming in contrast to its depletion under rainfall farming.

Studies show that more than one-half of the total weight of many plants is found below the surface, and under controlled moisture conditions as irrigation provides, field plants like alfalfa can be grown which send roots to a depth of 10 feet or more. Thus, the organic matter from this source is well distributed through the soil and is of great value.

[3] Reference by number is to "Literature Cited," p. 832.

Jordan (3) states that the effect of bringing non-irrigated soils under irrigation may be similar to that of transporting them to a humid environment. In his study where alfalfa has grown for several years, considerably greater amounts of both nitrogen and organic carbon were found. The increase in organic carbon is attributed in part to the accumulation of leaves lost in harvesting the alfalfa and in part to greater root development in the irrigated soil. The increase in nitrogen is attributed largely to the same causes accompanied by symbiotic nitrogen fixation.

Sievers and Holtz (6) state that, according to their investigation, the soil organic matter fluctuates with soil nitrogen and cannot be materially increased nor decreased unless soil nitrogen is similarly modified, and that it is not unusual to find in western irrigated sections soils growing richer instead of poorer in organic matter with cropping as a result of the increased moisture.

Burgess (1) states that it has been found uneconomical in Arizona to increase permanently the organic content of irrigated soils to any large degree, since decomposition processes, both biological and chemical, are extremely rapid owing to high temperatures, optimum moisture conditions, and good aeration. His results indicate that algae may be important contributors to the accumulating organic matter in irrigated soils, and that organic matter which is very low in virgin arid soil does not appear to be nearly as important quantitatively to most cultivated plants when subsequently grown under irrigation as is the case when these plants are grown in humid sections.

EXPERIMENTAL

A chemical study was made of Amity silty clay loam taken from 14 plats which are located in the irrigation field at the Oregon Agricultural Experiment Station, and which had been cropped for 15 years. The soil has a reaction of about pH 5.5 and lime requirements of 1½ to 2 tons per acre. The soil developed under a sub-humid climate with rather dry summers and 42 inches annual precipitation. White beans have been grown annually in comparison with a three-year rotation of barley, alsike clover, and beans. One series of seven tenth acre plats is irrigated, while the other seven are dry farmed. Three of the plats in each series are given 10 tons of barnyard manure per acre each rotation. Representative soil samples analyzed were collected to a depth of 0–8 inches from each plat, on October 8, about a month after the crop had been removed.

Chemical analyses were made on each soil sample. Organic carbon was determined by the wet combustion method (2) and total nitrogen by the modified Kjeldahl method. The organic matter was obtained by multiplying the total nitrogen present by 20. Blanks were run on this acid soil type and indicate that inorganic carbonates were negligible. The plat treatments are given in Table 1, together with results of analyses.

A definite accumulation of nitrogen and of organic matter resulted from supplemental irrigation, or crop rotation, or manuring, and explains largely the marked increases in yield obtained from plats thus treated.

Crop rotation increased the nitrogen 224 pounds per acre to plow depth under rainfall farming and 380 pounds with irrigation farming.

Irrigation increased the nitrogen accumulated by rotation in 16 years 156 pounds in the plowed surface of an acre, while with irri-

TABLE 1.—*Soil nitrogen and organic carbon as affected by crop rotation, manuring, and irrigation at the Oregon Agricultural Experiment Station.*

Plat No.	1929 crop treatment	Total nitrogen	Organic carbon	Nitrogen-carbon ratio	Organic matter (nitrogen x 20)
		%	%		%
	A. Irrigated Series				
52	Beans continuous	0.1527	1.653	1:10.9	3.054
51	Beans rotated	0.1680	1.762	1:10.5	3.360
50	Beans manured and rotated	0.1818	2.034	1:11.2	3.636
49	Clover rotated	0.1750	1.621	1:9.4	3.500
48	Clover manured and rotated	0.2044	2.079	1:9.9	4.088
47	Barley rotated	0.1722	1.874	1:10.9	3.444
46	Barley manured and rotated	0.1902	1.937	1:10.2	3.804
Ave. 51, 49, and 47 rotated		0.1717	1.752	1:10.2	3.435
Gain due to rotation		0.0190	0.099	----	0.381
Ave. 50, 48, and 46 rotated and manured		0.1921	2.016	1:10.4	3.843
Gain due to rotation and manure		0.0394	0.363	——	0.789
Pounds gain in 2,000,000 lbs. soil rotated		380	1,980	——	7 612
Pounds gain in 2,000,000 lbs. soil rotated and manured		788	7,260	——	15,772
	B. Dry Series				
41	Beans continuous	0.1393	1.563	1:11.2	2.786
40	Beans rotated	0.1561	1.769	1:11.3	3.122
39	Beans manured and rotated	0.1661	1.858	1:11.2	3.322
38	Clover rotated	0.1505	1.599	1:10.6	3.010
37	Clover manured and rotated	0.1715	1.762	1:10.3	3.430
36	Barley rotated	0.1449	1.537	1:10.6	2.898
35	Barley manured and rotated	0.1619	1.705	1:10.5	3.238
Ave. 40, 38, and 36 rotated		0.1505	1.635	1:10.8	3.010
Gain due to rotation		0.0112	0.072	——	0.224
Ave. 39, 37, and 35 rotated and manured		0.1665	1.775	1:10.6	3.330
Gain due to rotation and manure		0.0272	0.212	——	0.544
Pounds gain in 2,000,000 lbs. soil rotated		224	1,440	——	4,480
Pounds gain in 2,000,000 lbs. soil rotated and manured		544	4,240	——	10,880

gation and manure added each three years the gain was 244 pounds. With manure used in each rotation the relative gain in nitrogen was 320 pounds when dry farmed and 408 pounds when irrigated.

The organic carbon was increased over 10 times and the organic matter about 20 times as much as the nitrogen. With humus-building legumes used in the crop rotation under irrigation the problems incidental to maintaining nitrogen and organic matter are not so great as in non-irrigated regions.

Chemical analyses of samples from the six bean plats failed to reveal significant differences in reaction, water-soluble or exchangeable bases, or water-soluble phosphorus. The nitrate content and nitrate-supplying power of the soil seemed to be increased with the humus-building treatments and the C:N ratio seemed to be narrowed slightly.

In the unirrigated range of this experiment a tenth acre plat cropped to beans continuously for 15 years has given an average yield of 6.81 bushels an acre. With beans grown after alsike clover, after barley in a three-year rotation, the average yield has been 11.07 bushels, or a gain of 4.26 bushels an acre. Where 10 tons of manure have been applied each third year in a rotation, a yield of 13.84 bushels per acre, or a gain of 7.03 bushels, has been obtained.

Supplemental irrigation alone increased the yield 2.17 bushels per acre. With rotation and supplemental irrigation, the yield was increased 9.3 bushels, and with irrigation, rotation, and manure, 14.41 bushels per acre. The yield with irrigation, rotation, and manure has been about 3½ times that from continuous bean growing under rainfall farming.

The average net profit per acre (Table 2, column 5) has been calculated by using a price of 6c a pound for the beans, with a charge of $20 an acre for production under dry farming, $1 an acre inch for supplemental irrigation provided by pumping, and 12c a bushel for harvesting the increase in yield as compared to the dry farm plat cropped annually with beans.

It will be noticed that under dry farming conditions with continuous cropping the average net profit per acre has been but $4.51. With rotation this increased to $19.34, and with rotation and manure to $25.46. With irrigation farming and continuous cropping, the profit was only $7.56 an acre. With rotation this increased to $32.36, and with rotation and manuring to $50.15.

Under dry farming, the gain in net profit per acre with rotation was $14.83 and with manure and rotation it was $20.95. With supplemental irrigation the use of water alone produced a gain in profit of $3.05, with rotation $27.85, and with rotation and manure $45.64.

The profit per acre inch of water, as shown in column 7 of Table 2, was $1.02 with continuous bean cropping, $9.28 with rotation, and $15.21 with rotation and manure. This latter figure represents a gain of nearly 600% for the combined treatments, while irrigation alone netted about 100% profit per acre inch over continuous cropping.

TABLE 2.—*Value for beans of crop rotation, manure, and irrigation at the Oregon Agricultural Experiment Station, 15-year average to 1929.*

Treatment	Irrigation, inches	Yield in bushels per acre	Gain in bushels per acre	Net profit Ave. per acre	Net profit Gain by irrigation and rotation	Per acre inch	Pounds of water per pound of dry matter
		Dry					
Continuous	—	6.81	—	$4.51	—	—	2,849
Rotated	—	11.07	4.26	19.34	$14.83	—	2,284
Rotated and manured	—	13.84	7.03	25.46	20.95	—	1,771
		Irrigated					
Continuous	3.0	8.98	2.17	$7.56	$ 3.05	$1.02	3,579
Rotated	3.0	16.11	9.30	32.36	27.85	9.28	2,245
Rotated and manured	3.0	21.22	14.41	50.15	45.64	15.21	1,492

The water cost per pound of dry matter produced, as shown in column 8 of Table 2, has been obtained by determining the soil moisture content at the time of crop emergence and again at the time of harvesting. The loss in soil moisture so determined added to the rainfall and irrigation, expressed in total pounds an acre of water used per pound of dry matter produced, has been computed. This water cost is highest under continuous cropping.

Low efficiency or high water cost is experienced with continuous cropping under rainfall farming. Rotation and manuring have made it possible to produce dry matter at about one-half the water cost if the figures for both rainfall farming and irrigation farming are considered. Under irrigation farming the water cost with rotation and manure is about two-fifths of the water cost with continuous cropping.

At the beginning of this experiment the yield of beans for the 14 tenth acre plats included in this experiment averaged approximately 12 bushels per acre. The yields for 1928, the fifteenth crop year, at the close of the fifth three-year rotation, was but 4.50 bushels for beans grown continuously under rainfall farming and only 4.83 bushels where grown continuously under irrigation farming. These yields represent a crop value below the cost of production. With rotation under rainfall farming, the yield was 10.83 bushels the fifteenth year, and under irrigation farming 29.15 bushels. With rotation and manure the last season's (1928) yield under rainfall farming was 14.66 bushels and with rotation and manure under irrigation it was 36.66 bushels. At 6c a pound this represents a gross crop value on the last-named plat of $131.98 an acre.

These striking differences in yield, net profit, returns an acre inch, and water requirement are correlated with marked differences in nitrogen, organic matter content, improved nitrate-supplying power, water capacity, and biological activities in the soils studied.

Crop rotation permits the irrigation farmer to incorporate in the soil bulky nitrogenous organic matter which will improve the water capacity and physical condition of the soil and add active decaying organic matter, increase the activity of beneficial micro-organisms, and increase the concentration of the soil solution so that less water is required per unit of dry matter produced. Legumes make more root growth and aftermath with supplemental irrigation. The resulting effect upon productive land values in rainfall farming and especially with irrigation farming is very striking.

Crop rotation and the use of available farm wastes will usually insure a net profit in general farming or in irrigation farming. At the Oregon Experiment Station crop rotation has been about 85% as efficient as complete fertilizer for maintaining the yields of a typical soil over a 15-year period. Crop rotation is of primary importance in increasing the efficiency and net returns per unit of irrigation water. In selecting irrigation settlers on new projects it would seem that an agreement to practice a good rotation of crops, including one or more legumes, should be one of the primary requirements.

CONCLUSIONS

1. Marked increases in nitrogen and total carbon were found after 16 years from irrigation or crop rotation or use of manure each rotation.

2. The ratio of soil nitrogen to total carbon tended to remain fairly constant throughout the plats studied. The nitrate-supplying power of the soil appeared to increase, but other changes in the supply of readily available nutrients were not definitely significant.

3. Striking differences in crop yield, yield per acre inch, net profit per acre, and water cost of dry matter are found to be related to increases in soil nitrogen and total carbon.

4. Insisting that settlers on newly irrigated arid land practice a crop rotation for improving the nitrogen and organic matter content should go far toward insuring economical use of water and establishment of profitable crop production under irrigation.

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VARIABILITY OF GRAIN SORGHUM YIELDS AS INFLUENCED BY SIZE, SHAPE, AND NUMBER OF PLATS[1]

Arthur F. Swanson[2]

Many experiments have been conducted with field and orchard crops to determine the most suitable size, shape, and number of plats necessary to obtain reliable comparisons of yield. Such experiments on sorghums seem to be limited to those reported by Stephens and Vinall (3).[3] They sub-divided a field of feterita at Chillicothe, Texas, into 2,000 rod-row units. The rows were 40 inches apart and the rod-row units were equivalent to an area of approximately 1/800 acre. The total green weight of the forage in ounces from each unit was used as the basis for computation. From various combinations of the ultimate units into larger plats they concluded that three or four plats, 1/40 to 1/80 acre in size, gave results sufficiently reliable for determination of forage yields of sorghums.

This paper presents data on the influence of size and shape of plats and the number of replications on the variability in the yields of sorghum grain. The data were obtained at the Fort Hays Branch Experiment Station, Hays, Kansas, during the fall of 1923.

PLAT AND NURSERY METHODS IN USE

A questionnaire was sent recently to investigators located at agricultural experiment stations in the sorghum belt to ascertain the size, shape, and number of plats used in varietal tests. Twenty-three replies were received.

Four investigators favored plats less than 1/25 acre in area; 9 used 1/25 acre plats; 6 used 1/10 acre plats; and 6 used no definite size in their experiments. Two investigators favored plats with 2 rows; 6 used plats of 2, 3, or 5 rows; 12 used 4-row plats; and 3 used plats of 8 to 10 rows. As to length, 4 investigators used plats less than 100 feet long; 12 used plats 132 feet long; and 6 used plats of various lengths. The most popular widths between rows were 40, 42, and 44 inches.

The number of replications used varied widely. Five investigators planted single plats on one date, while 9 planted single plats on from two to four dates. Four investigators planted 2 plats of each variety on a single date, 2 used 2 plats for each variety on two different dates,

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., in cooperation with the Kansas Agricultural Experiment Station and the Fort Hays Branch Experiment Station, Hays, Kan. Received for publication April 21, 1930.

[2] Associate Agronomist.

[3] Reference by number is to "Literature Cited," p. 838.

and another made two plantings of each variety on three different dates. One investigator planted each variety three times on four different dates and another planted each variety four times on one date.

From the above it appears that the common practice is to plant single 4-row plats 132 feet long and approximately 1/25 acre in size on more than one date. Planting a variety in single plats on two to four dates technically is not replication. This practice is useful, however, in bringing to light many interesting facts regarding the response of sorghums to environmental conditions.

The length of nursery row used by the different investigators ranged from 2 to 10 or more rods. Four rods is a convenient length for a sorghum nursery row. A well-developed sorghum head will furnish sufficient seed for planting two 4-rod rows and leave enough reserve seed to repeat the planting in case a stand is not obtained. A row 4 rods long will produce 75 to 90 plants, a sufficient number for a fair expression of the characteristics of a strain, although not necessarily giving a reliable index of yielding ability.

EXPERIMENTAL METHODS

A pure line selection of Dawn kafir, a variety widely grown in the sorghum belt, was planted in rows 40 inches apart with a surface planter on a well-prepared field at Hays, Kansas, in 1923. This field had been uniformly cropped to wheat the previous year and had been fall plowed. The plants were thinned to a uniform stand 7 inches apart in the row, but there were occasional spaces in the rows having no plants. The largest vacant space in any row was 8 feet in length. In general, the stand was excellent for a field of grain sorghum.

At harvest time a block 50 rows wide and 16 rods long was laid out in the center of the field. The grain was harvested in single-row units 2 rods long, equivalent to an area of approximately /400 acre. The yields of each ultimate row were recorded in bushels per acre. Four hundred units were harvested. Since the entire block was in the center of the sorghum field, there was no border effect on any unit.

Ultimate plats varied in yield from 7.1 bushels to 62.5 bushels, but the means of the yields of the various combinations of plats, from 10 up, fluctuated only slightly from the average yield of 31.9 bushels.

Throughout this paper the term "replication" indicates the actual number of plats used and not the number plus one. The formula $0.6745\sqrt{\frac{\Sigma d^2}{n}}$ was used to determine the probable error of the yield of a single plat in all calculations presented here.

REDUCTION OF PROBABLE ERROR BY INCREASING SIZE OF PLATS

The reduction of the probable error due to increasing the size of plat by grouping adjacent plats is shown in Table 1. Whenever possible in a series of increasing size, either the length or the width of the plats was kept constant and the area enlarged by additions in the other dimension. As noted in Table 1, the decrease in probable error is not great after the plat has been increased in size to 1/25 of an acre or more. Increasing the plat from 1/400 of an acre to 1/25 of an acre (8 rods by 13 1/3 feet, a size frequently used) reduced the probable error 54.8%. Increasing the size to 1/10 of an acre reduced the probable error 60.9%. This slight reduction is not sufficient to justify the use of plats as large as 1/10 acre in variety tests of sorghums.

The probable errors shown in Table 1 for the larger plats, i.e., 1/8, 1/6, and ¼ of an acre, are based on a small number of plats and, since no additional land was added to the experiment, less reliability can be placed on the results.

TABLE 1.—*Reduction of probable error by increasing the size of plat of Dawn kafir.*

Approximate size of plat (acre)	Dimensions of plat Length in rods	No. of rows	Width in feet	Probable error of yields of single plats (bushels per acre)
1/400	2	1	3 1/3	7.57
1/200	2	2	6 2/3	6.87
1/100	2	4	13 1/3	5.82
1/66	2	6	20	5.57
1/50	2	8	26 2/3	5.46
1/40	2	10	33	5.42
1/200	4	1	3 1/3	6.59
1/100	4	2	6 2/3	6.12
1/50	4	4	13 1/3	5.10
1/33	4	6	20	4.86
1/25	4	8	26 2/3	4.83
1/20	4	10	33	5.02
1/100	8	1	3 1/3	4.16
1/50	8	2	6 2/3	4.39
1/25	8	4	13 1/3	3.42
1/16	8	6	20	2.73
1/12	8	8	26 2/3	2.99
1/10	8	10	33	2.96
1/50	16	1	3 1/3	4.38
1/25	16	2	6 2/3	4.07
1/12	16	4	13 1/3	2.93
1/8	16	6	20	2.59
1/6	16	8	26 2/3	2.68
¼	16	12	40	2.10

EFFECT OF SHAPE OF PLAT ON PROBABLE ERROR

Probable errors of plats of the same size but of different shape are presented in Table 2. The most satisfactory length for a plat appears to be about 8 rods. Moreover, long narrow plats are more convenient to harvest than square plats and are almost universally used in sorghum varietal testing. The probable errors are slightly less for long narrow plats than for those more nearly square in shape. In a field of level or nearly level contour, soil heterogeneity is likely to be more evident in small spots or areas than by progressive variation.

TABLE 2.—*Probable errors of the yields of plats of the same area but of different shapes.*

Approximate size of plat (acre)	Dimensions of plat			Probable error of yields of single plats (bushels per acre)
	Length in rods	No. of rows	Width in feet	
1/100	2	4	13 1/3	5.82
	4	2	6 2/3	6.12
	8	1	3 1/3	4.16
1/50	2	8	26 2/3	5.46
	4	4	13 1/3	5.10
	8	2	6 2/3	4.39
	16	1	3 1/3	4.38
1/25	4	8	26 2/3	4.83
	8	4	13 1/3	3.42
	16	2	6 2/3	4.07

REDUCTION OF PROBABLE ERROR BY REPLICATION

For the purpose of studying the value of replication, the variability of yield was computed for varying numbers of one to six systematically distributed plats, as shown in Table 3. As expected, the probable error decreased as the number of replications was increased. Even when the combined area of a replicated series of plats was no greater than the area of a single plat, the probable error was materially reduced by replication. As an illustration, the probable error of a single 1/25 acre plat consisting of four contiguous 8-rod rows was 3.42 bushels per acre, while the probable error of four single 8-rod rows systematically distributed was 2.08 bushels per acre, a reduction of 39.2%. Similarly, the probable error of four replications of 2-row plats 8 rods long by 6 2/3 feet wide is 1.39 bushels, while for the same area in two replications of four 8-rod rows the probable error is 2.97 bushels.

Within reasonable limits as to size of plats in a restricted area, the use of a larger number of replications and smaller plats can be expected to reduce the probable error more rapidly than the use of larger plats and fewer replications.

TABLE 3.—*The probable error of Dawn kafir yields as influenced by replication.*

Approximate size of plat	Dimensions of plat			Probable error of yields in bushels per acre with the number of replications indicated					
(acre)	Length in rods	No. of rows	Width in feet	1	2	3	4	5	6
1/400	2	1	3 1/3	7.57	5 64	3.79	4.53	2.79	2.44
1/100	2	4	13 1/3	5.82	4.40	2.26	3.25	3.32	1.47
1/50	2	8	26 2/3	5.46	3.82	1.98	2.99	2.79	1.21
1/200	4	1	3 1/3	6.59	4.88	3.67	3.96	2.29	1.98
1/100	4	2	6 2/3	6.11	4.49	3.45	3.59	2.08	1.21
1/50	4	4	13 1/3	5.10	3.31	2.55	2.69	1.50	0.81
1/100	8	1	3 1/3	4.16	3.91	2.43	2.08	1.66	1.06
1/50	8	2	6 2/3	4.38	3.79	1.60	1.39	1.57	0.05
1/25	8	4	13 1/3	3.42	2.97	2.08	0.85	1.06	0.64
1/12	8	8	26 2/3	2.99	2.79	0.05	1.67	—	—
1/10	8	10	33	2.96	2.79	1.17	0.67	0.02	—
1/50	16	1	3 1/3	4.38	2.63	2.20	2.24	1.04	1.81

The fact should not be overlooked that results recorded in Table 3 can be obtained only when the same area of land is used as a basis for all calculations, and the results may not be applicable to another set of conditions. With such crops as sorghums, when border rows are used, the additional land required is often increased from one-third to one-half. When such additional land is required for this or other reasons, the larger area taken into the experimental block increases the chances of encountering more variable land. Large areas of uniform land usually are not available. The cost of conducting an experiment and the opportunity for mechanical errors of various sorts also are increased with replication. Therefore, in practice. the number of replications usually is less than the results in Table 3 indicate as being desirable.

In connection with the study of replicating plats to correct for soil heterogeneity, consideration must be given to the fact that climatic variations from year to year are very great in the Plains region. The standard deviations in yields for the several major crops at the Hays station are greater than the mean yields for the same crops over a period of years. The variations in yield from one season as compared to another have been known to fluctuate from 0 to 65 bushels per acre for an adapted variety of sorghum. Still more disturbing is the order in which varieties are influenced by seasonal variation. The need of sampling the seasons over a period of years is as important as providing means for correcting errors due to soil heterogeneity. The magnitude of error from seasonal variation has been pointed out by Engledow and Yule (1) and by Stadler (2).

Perhaps the chief causes for variations in sorghum yields under a given set of conditions, in addition to soil heterogeneity and environment, are uneven stands and disturbances from methods of cultivation. The sorghum plants are delicate and slow growing in the early stages of growth. Replication is desirable, therefore, because it is sometimes necessary to discard a plat having a poor stand or because the plants have been injured or destroyed by mechanical or uncontrolled causes.

Sorghum plants are larger and require more space than plants of small grains and larger plats usually have been considered necessary. Results here obtained indicate that grain sorghums require about the same number and size of plats as other field crops for dependable experimental results.

SUMMARY

The reduction in probable error of grain sorghum yields is not great after the plat has been increased in size to 1/25 acre. Long narrow plats seem the most reliable for varietal trials and certainly are the most practical from the standpoint of economy. The probable error is slightly lower for long narrow plats than for square plats of the same area. When protected by borders, 2- to 4-row plats 8 rods long having an area from 1/50 to 1/25 acre are desirable and convenient units.

Since the average yields of grain sorghums on the field stations in the Great Plains are less than 30 bushels per acre, two to four replications of a variety should usually reduce the probable error to 1 to 3 bushels per acre when 1/50 to 1/25 acre plats are used. For dependable results, it is also necessary to grow varieties for a sufficient number of years to sample the seasons which vary greatly in the Great Plains area.

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PASTURE TOP-DRESSING WITH FERTILIZER AND LIME IN THE HAY AND PASTURE BELT[1]

J. B. ABBOTT[2]

During the season of 1929, a group of agronomists associated with the fertilizer industry cooperated in conducting 103 replications of a uniform pasture top-dressing test in 15 northeastern states and in the Province of Ontario. This paper is a progress report and summary of the first season's results.

The plat arrangement and treatment of the standard test was as follows:

Check, untreated
Phosphoric acid only,* 1,000 pounds per acre 0–10–0†
Phosphoric acid and lime, 1,000 pounds per acre 0–10–0 and lime
Phosphoric acid, potash, and lime, 1,000 pounds per acre 0–10–10 and lime
Complete fertilizer and lime, 1,000 pounds per acre 5–10–10 and lime

*625 pounds 16% superphosphate actually used.

†The figures refer to percentages of nitrogen, phosphoric acid, and potash, respectively. The nitrogen was derived from either ammonium sulfate, calurea, cyanamid, nitrate of soda, or any mixture of them. The phosphoric acid was derived from superphosphate, usually 16%. The potash was derived from muriate of potash. The lime used was either 2,000 pounds per acre of hydrate or 3,000 pounds per acre of carbonate.

Each plat was 2 by 8 rods in size, making 1/10 acre. Cattle were fenced out of one end of each plat from the start so that growth response could be observed and determined by mechanical harvesting and chemical analysis. Field men were given the following suggestions relative to handling these tests:

> "Locate plats on pasture land which is reasonably free from brush, reasonably well supplied with moisture, and not exhausted to the point where the desirable species of pasture plants have completely disappeared.
>
> "In general, select land which once grew good pasturage and avoid like a pestilence land which never did. Avoid especially land which existing vegetation marks as excessively droughty.
>
> "Apply all treatments except nitrogen in the fall or as early as possible in the spring. Apply nitrogen about a month before 'turning out time.' "

The average result, together with estimated cost and comparative cost of dry matter and crude protein in three of the commoner manger

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[1] Paper read at the annual meeting of the Society held in Chicago, Ill., November 15, 1929. Received for publication April 21, 1930.

[2] National Fertilizer Association, Bellows Falls, Vt.

feeds, is set forth in Table 1. Correlation of agronomic response with soil type, rainfall, or character of vegetation does not appear to be possible on the basis of the data at hand.

Observation and comparison of the clipped and of the normally grazed areas during the season indicated that mechanical harvesting as practiced failed to simulate natural grazing closely enough to have the same effect upon the character and composition of the sod after mid-summer with respect to both percentage of clover in the stand and density of the stand of grass. It is believed that both the percentage of clover in the harvested material and total yield were adversely affected as compared with normal grazing. It seems probable that more accurate results would be secured by the use of movable cages, the cages being moved onto a grazed area after each clipping.

A further unavoidable weakness of the method used is that, as compared with normal grazing, there was no return of plant food to the harvested areas in the form of animal excrement during the season. Under natural grazing conditions that is an important

TABLE 1.—*Summary of first year's results of 103 pasture top-dressing tests in 15 northeastern states and Ontario, with estimated annual cost of treatment, cost per 100 pounds of dry matter and protein produced, and comparison with cost of dry matter and protein in common manger feeds.*

Experimental treatments Fertilizer ½ ton Lime 1 ton	Untreated check	0–10–0 ——	0–10–0+ lime	0–10–10+ lime	5–10–10+ lime
First year cost per acre:					
Lime @ $10 per ton	——	——	$10.00	$10.00	$10.00
Nitrogen @ $3.20 per unit	——	——	——	——	8.00
P_2O @ $1.25 per unit	——	$6.25	6.25	6.25	6.25
K_2O @ $1.25 per unit	——	——	——	6.25	6.25
Labor sowing lime	——	——	1.00	1.00	1.00
Labor sowing fertilizer	——	1.00	1.00	1.00	1.00
Interest, taxes, and fencing	$1.80	1.80	1.80	1.80	1.80
Total	$1.80	$9.05	$20.05	$26.30	$34.30
Est. annual cost per acre*	$1.80	$4.21	$6.41	$8.49	$17.16
Ave. yield per acre, 103 tests:					
Pounds dry matter	1,051	1,392	1,548	1,850	2,501
Pounds crude protein	177	235	266	344	488
Cost per 100 pounds, basis all treatments charged against first year:					
Dry matter	$0.17	$0.65	$1.17	$1.42	$1.37
Crude protein	1.05	3.93	6.86	7.64	7.02
Cost per 100 pounds, basis estimated annual cost:					
Dry matter	$0.17	$0.30	$0.41	$0.46	$0.68
Crude protein	1.05	1.79	2.41	2.46	3.52

Cost per 100 pounds:	In clover-timothy hay @ $20.00	In silage and soiling crops @ $7.00	In 20% protein dairy feed @ $50.00
Dry matter	$ 1.14	$ 1.40	$ 2.77
Crude protein	11.63	17.50	12.50

*Assumed that, in the amounts used, nitrogen will last one year, P_2O_5 and K_2O, three years, and lime five years.

factor in maintenance of yield. This factor, of course, would tend to make the yields as secured under- rather than over-estimates of the response which would be secured by actual grazing.

While it is, of course, unsafe to draw final conclusions from only a single season's results, the present indications are that each added material, at least when added in the order in which they were used in this test, increases the total yield, the percentage of protein, and the cost per unit of nutrients; but that even the most expensive treatment results in nutrients from the pasture at a cost materially below their cost in manger feed.

When the results of pasture fertilization are measured by the yardstick of quantity, quality, time, and place, it appears that the more intensive treatments usually are more effective than the extensive treatments with respect to total yield, percentage of protein and minerals, earliness of good grazing (ten days to two weeks in the case of the complete fertilizer and lime treatment), and persistence of good grazing into the latter part of the season.

If those indications are supported by further experience, it would seem to follow that it is profitable to fertilize pasture in those cases where the farmer fails to secure without fertilization enough nutrients of the right quality, at the right time, and in the right place; and that, while the treatment should not be more intensive than is required to meet the needs, it may be as intensive as is necessary to produce the desired response and still produce nutrients below their cost in manger feeds.

In those cases where large areas of responsive soil per animal unit are available, extensive treatment of large areas would seem to be indicated as the best practice, while, on the other hand, in cases of limited areas of responsive soil per animal unit, with manger feeding or semi-starvation as the alternative, intensive treatment of those limited areas would appear to be equally clearly indicated.

In this connection it may be pertinent to observe that large areas of so-called pasture land do not necessarily mean the same thing as large areas of responsive soil, since there is a great deal of unresponsive land included in the present pasture area.

WILTING COEFFICIENT STUDIES[1]

A. V. CAPALUNGAN AND H. F. MURPHY[2]

The amount of available moisture present in a soil is of great importance, particularly when it is considered in connection with the critical moisture periods for the growth and development of a given crop. The limit to which a plant can remove moisture from a soil depends on the crop, soil, and climate. Various relationships have been used for this lower limit of available moisture, but perhaps that of wilting coefficient receives greatest consideration.

Briggs and Shantz (3)[3] have done considerable work studying the wilting coefficient of soils. Their publications are well known and the formula offered by them that the wilting coefficient equals the hygroscopic coefficient divided by 0.68 ± .012 is found in texts treating on this subject.

Many other investigators, a few of whom are Loughridge (6), Powers (7), Alway (1), Batchelor and Reed (2), Brown (4), Caldwell (5), and Shive and Livingston (8), have likewise contributed to the list of publications on available moisture studies.

The writers studied the wilting coefficient for a number of Oklahoma soils using several crops common to the section. The method used in determining the wilting coefficient was essentially that described by Briggs and Shantz (3). In all cases at least three tumblers were used and in most cases at least five and often many more were used in securing the data on any particular soil for a given crop. The tabulated results are given in Table 1.

The well-known effect of soil texture on the lower available moisture limits is shown in the table. The table also shows that different crops vary somewhat in their ability to reduce soil moisture. This is better understood from Table 2. The third column of Table 2 shows the relative ability of the various crops to reduce the moisture content of the soil. If the mean ratio is less than unity, it means that that crop was more efficient in reducing the moisture content than where the mean ratio was unity or greater.

It is interesting to note that oats which require more water per pound of dry matter than the other crops reduces the soil moisture to the lowest level of any of the small grains. Rice which is more of a water plant in its wild state comes next. Of the grain sorghums,

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[1] Contribution from the Department of Field Crops and Soils, Oklahoma A. & M. College, Stillwater, Okla. Received for publication April 22, 1930.

[2] Graduate student and Associate Professor of Soils, respectively.

[3] Reference by number is to "Literature Cited," p. 847.

TABLE I.—*Showing the wilting coefficient of different soils and crops.*

Crop	Derby fine sand	Knox fine sand	Yahola fine sandy loam	Canadian fine sandy loam	Vernon fine sandy loam	Kirk-land loam	Kirkland silt loam*	Yahola silt loam	Kirkland loam	Miller fine sandy loam
Silvermine corn	1.41	1.90	3.89	5.31	6.67	10.38	8.27	11.38	9.27	11.81
Darso	1.29	1.55	3.36	4.92	5.48	8.76	7.68	10.48	9.32	—
Reed's kafir	1.45	1.54	—	4.92	6.49	8.98	8.43	10.45	11.79	9.89
Kanred wheat	1.34	1.66	4.89	5.20	6.43	8.80	9.65	—	10.11	10.97
Whippoorwill cowpeas	2.06	—	3.61	4.52	5.93	—	7.92	7.95	10.30	9.90
Common alfalfa	1.35	—	4.14	4.71	—	7.83	7.60	8.40	9.77	10.24
Reid's Yellow Dent corn	—	—	3.38	—	—	8.42	8.68	8.73	9.88	11.39
Yellow milo	—	—	3.80	—	—	—	8.48	—	—	—
Barley	—	—	4.07	—	—	7.05	8.47	—	—	—
Oats	—	—	3.58	—	—	7.00	7.60	8.85	9.37	—
Rice†	—	—	3.59	—	6.51	—	7.56	9.28	7.90	—
Okla. Triumph No. 44 cotton	—	—	—	5.03	6.10	8.89	8.61	9.88	9.03	10.35
Feterita	—	—	—	—	—	7.36	7.14	8.55	8.27	—
Sweet clover	—	—	—	—	—	8.43	7.92	—	9.06	—
Turkey red wheat	—	—	—	—	—	—	—	9.45	—	—
Mean wilting coefficient	1.47	1.66	3.85	4.94	6.29	8.23	8.06	9.28	9.47	10.65

*This technically would be classified as a loam, but it is quite heavy.

†Included only because of interest; not grown in Oklahoma.

TABLE 2.—*Relative efficiency of different plants to reduce the moisture content.*

Crop	No. of observations	Mean ratio
Common alfalfa	30	0.97
Barley	10	0.98
Okla. Triumph No. 44 cotton	32	1.01
Silvermine corn	62	1.09
Reid's Yellow Dent corn	24	1.02
Whippoorwill cowpeas	23	0.97
Sweet clover	7	0.98
Texas Red oats	10	0.94
Rice	10	0.95
Darso	60	0.99
Feterita	8	0.90
Reed's kafir	52	1.06
Yellow milo	5	1.01
Kanred wheat	52	1.04
Turkey Red wheat	10	1.01
Weighted mean		1.00

feterita shows the lowest ratio and hence the greatest ability to reduce soil moisture. The number of determinations with this crop was somewhat small, but close checks were secured in every case. Darso which is commonly known in central Oklahoma as a relatively drouth resistant crop showed a somewhat greater tendency to reduce soil moisture than did Reed's kafir. The results with Reed's kafir and darso conform to the yield results secured in the section. Yellow milo data show it to be a little more effective in reducing soil moisture than Reed's kafir, although the number of determinations made with this crop is too low to draw definite conclusions. In the drier parts of the state adapted to grain sorghums this crop is the major sorghum grown.

All of the legumes showed a wilting coefficient lower than unity. Wheat has a wilting coefficient a little higher than the average. As an average, corn reduced the soil moisture the least. The Silvermine variety used was less effective in reducing soil moisture than was Reid's Yellow Dent.

Another method of comparing the efficiency of different plants in their reduction of water for a given soil is by growing them simultaneously in the same pots. This is probably the best direct method of comparison since all influences of environmental conditions under which the plants are grown are practically eliminated. In this experiment Kanred wheat was the crop used with which to compare the other crops. Two wheat plants and two plants of the crop in question were grown in each pot. Table 3 gives the results for cotton, Silvermine corn, Reed's kafir, Reid's Yellow Dent corn, alfalfa, and darso, the crops which showed extreme ratios in Table 2.

TABLE 3.—*Wilting coefficients of some crops grown simultaneously in the same pots with Kanred wheat, using Kirkland loam.*

Wilting coefficient	Mean	Comparison with Kanred wheat
Oklahoma Triumph No. 44 cotton		
8.32		Wilting simultaneously
8.68		Wilting simultaneously
9.02		Wilting simultaneously
8.47		Wilting simultaneously
8.44		Wilting simultaneously
8.64		Wilting simultaneously
8.67		Wilting simultaneously
9.19		Wilting simultaneously
8.54		Wilting simultaneously
8.39		Wilting simultaneously
9.03	8.67	Wilting simultaneously
Whipperpoorwill Cowpeas		
8.72		Wilting simultaneously
9.22		Wilting simultaneously
8.87		Wilting simultaneously
8.36		Wilting simultaneously
9.09		Wilting simultaneously
8.76		Wilting simultaneously
8.65		Wilting simultaneously
8.60		Wilting simultaneously
8.49		Wilting simultaneously
8.70		Wilting simultaneously
8.68	8.74	Wheat wilted a little earlier
Common Alfalfa		
8.35		Wheat wilted a little earlier
7.76		Wheat wilted a little earlier
8.27		Wheat wilted a little earlier
8.28		Wheat wilted a little earlier
8.90		Wilted simultaneously
8.90		Wilted simultaneously
9.03		Wilted simultaneously
8.61		Wilted simultaneously
8.52		Wilted simultaneously
8.53	8.51	Wilted simultaneously
Silvermine Corn		
8.53		Corn wilted a little earlier
8.78		Corn wilted a little earlier
9.31		Corn wilted a little earlier
8.60		Corn wilted a little earlier
8.88		Corn wilted a little earlier
8.52		Corn wilted a little earlier
8.70		Wilted simultaneously
8.37		Wilted simultaneously
9.18		Wilted simultaneously
8.92	8.77	Wilted simultaneously
Darso		
8.83		Wilted simultaneously
8.83		Wilted simultaneously
8.64		Wilted simultaneously
8.85		Wilted simultaneously
8.25		Wilted simultaneously
8.06		Wilted simultaneously
7.85		Wilted simultaneously
8.00		Wilted simultaneously
8.37		Wilted simultaneously

TABLE 3—*Continued.*

Wilting coefficient	Mean	Comparison with Kanred wheat
Darso		
8.20		Wilted simultaneously
8.39		Wilted simultaneously
8.06		Wilted simultaneously
8.03		Wilted simultaneously
8.20		Wilted simultaneously
8.42	8.32	Wilted simultaneously
Reed's Kafir		
8.36		Wilted simultaneously
8.20		Wilted simultaneously
8.40		Wilted simultaneously
8.44		Wilted simultaneously
8.20		Wilted simultaneously
8.36		Wilted simultaneously
8.31		Wilted simultaneously
8.00		Wilted simultaneously
8.27		Wilted simultaneously

It will be seen that the results of the simultaneous experiment are practically in accord with those recorded in Tables 1 and 2. Silvermine corn, which showed a higher wilting coefficient than any other crop used in the experiment, wilted a little earlier than the wheat. Also, some of the determinations showed that wheat, with a ratio 0.03 greater than unity, wilted before alfalfa. In no case did the alfalfa wilt before wilting took place in the wheat plant.

SUMMARY

1. Wilting coefficients of some soils were studied using some important crops grown in western Oklahoma as indicators.

2. The wax-seal and unpervious-pot method of Briggs and Shantz was employed.

3. Soil texture showed its usual effects on retaining moisture against plant usage.

4. The formula for wilting coefficient secured by the writers was as follows:

$$\text{Wilting coefficient} = \frac{\text{Hygroscopic coefficient,}}{0.61 \pm .014},$$

which is not much different than that secured by Briggs and Shantz.

5. Crops differ somewhat in their ability to reduce soil moisture.

6. Of the small grains studied, including oats, wheat, and barley, oats reduced the moisture content to the lowest percentage.

7. Silvermine corn was the least effective of the crops studied in reducing soil moisture.

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HYBRID VIGOR IN OATS[1]

F. A. COFFMAN AND G. A. WIEBE[2]

Increased vigor frequently results from hybridization in cereal plants. This is observed by comparing the hybrid with its parents. Jamieson (5),[3] as early as 1897, reported increased vigor in oat hybrids. His use of the term hybrid seems open to criticism, however, as he believed that oats cross so freely that if he simply mixed the seed of two varieties and grew this mixture the resulting crop would be of a hybrid nature and from it he would derive, as he says, all the "benefits of crossing." He reports that his oat "crosses" gave a decided increase in grain yield, no increase in tillers per plant, and a variation in plant height as compared with the parents.

That oats cross naturally has been shown by the results of Stanton and Coffman (10), Griffee and Hayes (4), Garber and Quisenberry (2), and Coffman and Wiebe (1), but that they ever cross to the extent indicated by Jamieson is seriously doubted by the present writers.

With the exception of the work by Jamieson apparently no reports have been published of attempts to measure the extent of hybrid vigor in oats, and only a few studies of this phenomena seem to have been made in other small grain crops.

Griffee (3) studied the influence of hybridization on weight of seed or grain yield and plant height in wheat. He observed that in some crosses there occurred increased yield per hybrid plant, while in other crosses the reverse was observed. A study of hybrid vigor in rice was made by Jones (7). He observed increased height of plant, increased number of culms, and increased yield per plant in the F_1 generation plants. The study herein reported was similar to that of Jones. The difference between inbred strains of corn in their ability to influence heterosis in their hybrid progeny has been shown by Richey and Mayer (9) and by Jenkins (6).

MATERIALS AND METHODS

The experiments were conducted under irrigation at Aberdeen, Idaho, in 1927 and 1928. Hybrid vigor was studied in the F_1 and in

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[3] Numbers in parenthesis refer to "Literature Cited," p. 860.

a few crosses in the F_2. The relative influence of different parents on the vigor of their F_1 generation hybrids also was studied.

The crosses studied in the F_1 generation were as follows:

Cross No.	♀		♂
1	Burt (fatuoid)	X	Black Mesdag
5	Monarch	X	Black Mesdag
10	Richland	X	Fulghum
12	Richland	X	Markton
13	Richland	X	Markton
14	Fulghum	X	Markton
15	Ruakura	X	Burt (chlorotic)
17	Black Mesdag	X	Monarch
21	Burt (fatuoid)	X	Monarch
22	Black Mesdag	X	Monarch
35	Cornellian	X	Garton Gray
36	Garton Gray	X	Cornellian
37	Markton	X	Iogold
38	Edkin	X	Markton
39	Cornellian	X	Garton Gray
40	Silvermine	X	Edkin
42	North Finnish	X	Black Mesdag
52	Swedish Select	X	Fulghum (fatuoid)
53	Markton	X	Black Mesdag
54	Cornellian	X	Markton
55	Fulghum (fatuoid)	X	Black Mesdag

The influence of the varieties Markton, Black Mesdag, Richland, Cornellian, Monarch, and Garton Gray on the vigor of their F_1 generation hybrid progeny was studied. The F_1 plants were spaced at 1-foot intervals in rows 6 feet long and 1 foot apart. The hybrid plant rows alternated with parent plant rows, on the one side the pollen parent and on the other the ovary parent similarly spaced. Where for any reason a blank occurred the space was occupied by sowing Richland, a yellow, early, short, stiff-strawed oat.

In studying hybrid vigor in the F_1 the characters considered were (a) plant height, (b) panicle length, (c) number of culms, (d) total plant weight, (e) straw weight, (f) grain weight, and (g) date of heading. For determining plant weight, the plants were cut off just above the surface of the ground. Panicle length was determined by measuring what appeared to be the largest panicle on the plant, and plant height by measuring to the top of the panicle of the tallest culm. In studies of F_2 populations made in 1927, all the above characters, except date of heading, were considered. In studies of F_2 populations made in 1928, only grain yield was considered. Data involving measurements, counts, and weights were recorded at harvest. The panicles of each plant were removed and placed in envelopes. After drying they were weighed, threshed, and the seed weighed. The culms were retained for later weighing to recheck the straw weight. In studying the relative influence of parent strains on their hybrid progeny each hybrid plant was compared with the adjacent progeny plants of its respective parents, plants being chosen which were grown in so far as could be discerned under identical field conditions.

The F_2 and comparable parent material were sown at the rate of 100 kernels per 16-foot row.

TABLE 1.—*Average measurements of the parental plants and deviations of the F_1 hybrids from the means of their parents.*

Cross No. 1927	No. of plants	Plant height, cm	Panicle length, cm	No. of culms	Total weight in grams Plant	Total weight in grams Straw	Total weight in grams Grain	Date headed, July*
			Female Parents (Means)					
1	4	79.5	16.2	12.2	32.8	20.0	12.8	12.0
5	6	98.7	28.8	13.2	109.8	88.6	21.2	20.2
10	6	69.3	19.8	13.7	30.3	13.8	16.5	13.3
12	6	67.3	17.7	9.8	23.0	14.5	8.5	14.8
13	5	67.6	17.6	10.8	33.8	21.2	12.6	13.8
14	6	73.0	15.2	19.7	36.5	24.7	11.8	10.2
15	5	92.0	20.6	14.2	41.0	23.4	17.6	13.6
17	5	99.6	30.8	10.6	58.4	38.4	20.0	18.8
21	5	70.0	16.6	16.2	29.0	17.6	11.4	10.0
22	6	100.7	30.3	14.0	69.0	48.0	21.0	19.5
35	4	98.3	29.5	10.8	62.5	41.0	21.5	20.3
36	6	103.7	27.5	12.5	75.0	56.2	18.8	27.0
37	5	97.4	29.0	17.2	102.0	73.6	28.4	15.2
38	2	81.5	21.0	16.0	53.0	31.5	21.5	16.5
39	2	98.0	27.5	12.5	66.0	46.5	19.5	21.5
40	6	96.0	25.8	12.0	57.8	36.1	21.7	23.7
42	6	96.8	31.5	13.0	65.5	47.3	18.2	24.8
52	6	97.5	25.8	8.8	71.0	45.3	25.7	19.8
53	6	92.7	25.3	16.3	95.2	66.9	28.3	16.5
54	6	97.0	25.8	10.0	94.3	77.5	16.8	22.0
55	6	66.7	12.8	28.8	40.8	29.8	11.0	7.8
			Male Parents (Means)					
1	6	105.0	32.0	12.3	70.8	43.5	27.3	19.2
5	5	100.0	30.2	10.6	70.0	43.0	27.0	18.4
10	5	71.4	13.2	16.0	24.8	15.0	9.8	9.4
12	6	89.2	24.7	14.0	82.2	59.5	22.7	16.7
13	6	90.8	26.7	19.0	100.0	71.3	28.7	16.3
14	6	92.5	24.0	17.7	95.2	69.0	26.2	16.0
15	6	84.2	19.5	18.0	46.3	30.0	16.3	14.2
17	6	101.5	31.0	18.5	76.7	58.2	18.5	21.3
21	6	98.8	29.3	15.8	103.5	77.7	25.8	19.5
22	6	97.3	29.3	19.0	84.3	63.0	21.3	20.7
35	6	98.2	28.3	11.2	66.2	49.7	16.5	25.0
36	6	99.8	28.2	13.2	77.5	53.5	24.0	21.8
37	6	94.2	22.3	17.8	85.8	63.8	22.0	16.8
38	6	93.8	27.2	21.5	84.7	52.4	32.3	16.3
39	6	100.3	26.8	13.8	81.5	58.0	23.5	27.0
40	6	80.5	21.2	13.3	45.3	27.0	18.3	14.7
42	5	94.4	28.0	11.8	47.4	33.2	14.2	17.8
52	4	67.5	13.0	16.5	20.8	13.8	7.0	11.0
53	3	95.0	30.0	14.3	59.3	45.0	14.3	21.0
54	5	90.8	26.0	13.6	68.8	50.2	18.6	20.0
55	3	98.3	29.0	10.0	71.7	47.0	24.7	17.3

TABLE 1.—*Continued.*

Cross No. 1927	No. of plants	Plant height, cm %	Panicle length, cm %	No. of culms %	Total weight			Date headed, July*
					Plant	Straw	Grain	
	Average Deviation of Hybrids from Means of Largest Parent†							
1	1	—4.8	—34.4	+5.7	—23.7	—33.3	—8.4	—5.2‡
5	3	+5.0	+10.3	—14.4	—9.8	—24.0	+17.4	—2.9
10	4	+13.2	—22.7	+17.5	+48.5	+51.3	+35.2	—5.8
12	4	—1.3	—13.0	—8.6	—33.7	—53.8	+18.9	—3.9
13	1	—0.9	—21.3	—42.1	—47.0	—63.5	—9.4	—4.3
14	2	—9.7	—22.9	—8.6	—32.2	—34.1	—27.5	—6.5
15	1	+8.7	+1.9	—5.6	+29.6	+10.0	+53.4	—2.2
17	1	+0.5	+3.2	—18.9	—3.5	—17.5	+30.0	—1.3
21	1	—10.0	—1.0	—25.9	—54.6	—70.4	—7.0	—7.5
22	1	+0.3	—14.2	—15.8	—6.3	—12.7	+12.7	——
35	1	+9.9	+1.7	—19.6	+32.9	+8.7	+5.8	±0.0
36	2	—0.7	+9.9	—16.7	—16.1	—17.3	—22.9	±0.0
37	2	—1.4	—15.5	—27.0	—20.1	—21.2	—17.3	+2.7
38	1	—12.6	—15.4	—44.2	—55.1	—59.9	—47.4	—3.5
39	2	+5.7	+7.3	—16.7	—14.1	—17.2	—6.4	—2.0
40	5	—4.4	±0.0	—8.3	+4.5	+8.0	—1.4	—6.3
42	5	+3.7	+0.3	+3.1	+16.3	+14.6	+20.9	—4.6
52	4	—12.6	—29.1	+9.1	—24.9	—34.2	—8.6	—10.0
53	2	—3.2	—16.7	—44.8	—54.3	—56.7	—48.8	—7.5
54	2	—3.1	+5.8	—15.4	—41.7	—45.8	—30.1	—6.5
55	1	—13.5	—41.4	—41.0	—38.6	—44.7	—27.1	—12.3
	Average Deviation of Hybrids from Means of Both Parents†							
1	1	+8.3	—12.9	+6.5	+6.3	+8.8	+24.4	—1.6
5	3	+5.6	+12.9	—5.0	+10.1	+2.3	+31.5	—2.0
10	4	+14.8	—7.3	+26.2	+63.0	+57.6	+68.9	—3.9
12	4	+12.4	+1.4	+7.6	+3.6	—25.7	+73.1	—3.0
13	1	+13.6	—5.4	—26.2	—20.8	—43.8	+25.6	—3.1
14	2	+0.8	—5.6	—3.7	—2.1	—3.0	±0.0	—3.6
15	1	+13.5	+4.5	—5.6	+37.3	+23.6	+58.8	—1.9
17	1	+1.4	+3.6	+2.7	+9.5	—0.6	+34.7	—0.1
21	1	+5.5	+26.1	—25.0	—29.1	—51.8	+29.0	—2.8
22	1	+2.0	+12.8	—3.0	+3.0	—0.9	+13.2	——
35	1	+9.9	+3.8	—18.2	+36.6	+18.9	+78.9	+2.3
36	2	+1.2	+11.1	—14.7	—14.8	—15.3	—13.6	+2.6
37	2	+0.2	—4.7	—25.7	—13.2	—15.6	—6.7	+3.5
38	1	—6.5	—4.6	—36.2	—44.8	—50.0	—36.8	—3.4
39	2	+6.9	+8.5	—12.9	—5.1	+8.2	+2.3	+0.7
40	5	+4.0	+9.8	—3.9	+17.1	+23.4	+7.0	—1.8
42	5	+5.0	+6.0	+8.1	+34.9	+34.5	+35.8	—1.1
52	4	+3.3	—5.7	—4.7	+16.1	+0.7	+43.3	—5.6
53	2	—2.0	—9.7	—41.2	—43.7	—48.2	—31.9	—5.3
54	2	+0.1	+6.2	—25.4	—32.6	—34.2	—26.6	—5.5
55	1	+3.0	—18.7	—12.4	—29.0	—32.3	+0.6	—7.6
Mean % or days		+4.9	+15.3	—11.89	+0.11	6.8	+19.6	—2.16

*Deviation in days headed, the minus sign meaning earlier, the plus sign meaning later.

†The minus sign means less than, the plus sign more than mean of parents.

‡Deviation from the later headed parent, minus meaning earlier and plus meaning later.

STUDY OF THE F_1 GENERATION

The vigor study on the F_1 hybrids was conducted in 1927 only. Data on plant characters of the F_1 hybrids compared with their parent populations are given in Table 1, and in general show that, while the hybrids often exceeded their parental mean in size, they less often exceeded the mean of the largest parent, indicating that marked increase in vigor was the exception rather than the rule.

PLANT HEIGHT

The mean increase in plant height of the 21 crosses over the mean height of their respective parents was 4.2 cm, or 4.9%. Parental strains varied so widely in height, however, that mean data may not be significant. Based on averages, data for plant height of the 21 crosses show that in only two populations were the hybrids shorter than the mean height of their respective parents. The plant height of the hybrids exceeded that of both parents in 8 of the 21 crosses. The other crosses were intermediate to the parents in varying degrees. In one case the plant height of the hybrid was less than that of either parent. In most of these crosses plant height was increased by hybridization, but the amount of increase varied widely with variety. Data showing comparative vigor of different parents and hybrids are given in Table 2.

Markton, a normally tall variety, apparently possesses most of the height factors present in the other varieties with which it was crossed. Crosses involving Markton showed little increase in height over Markton itself. When Black Mesdag, Monarch, Garton Gray, Richland, or Cornellian were used as parents, there was some increase in height in some of the hybrids, although no conclusive increase occurred in others.

LENGTH OF PANICLE

The mean panicle length of the hybrid plants was 0.186 cm, or 1.53%, longer than that of the parent strains. Eleven crosses produced plants having panicles with a mean length greater than that of their parents, and ten crosses had a mean panicle length shorter than that of their parents.

Only eight hybrids produced plants having panicles longer than those of either parent strain. Two hybrids produced panicles shorter than those of either parent. Six hybrids were equal or practically equal in panicle length to one or the other of the parents. The data on panicle length are so variable that they indicate no consistent influence from hybridization. In some crosses hybridization may increase panicle length slightly, while in others no increase is shown.

There was little evidence of increased panicle length in hybrids of Markton and Richland (Table 2). Cornellian, Garton Gray, and possibly Monarch apparently contributed factors for panicle elongation. Black Mesdag, which has large panicles, gave widely different results in different crosses. There is evidence of difference in parental influence on the panicle length of hybrid progeny.

TABLE 2.—*Mean or average influence of different varieties used as parents of F_1 hybrids on the vigor of the progeny plants as shown by study of several different characters.*

		Comparison of hybrids with size of parents				
			Ranking between parents			
Parent considered	No. of crosses made	Exceeded both	Upper third	Middle third	Lower third	Less than both
		Plant Height				
Markton	7	–	2	2	2	1
Black Mesdag	7	4	1	1	–	1
Richland	3	1	2	–	–	–
Cornellian	4	2	1	1	–	–
Monarch	4	3	–	1	–	–
Garton Gray	3	2	1	–	–	–
		Panicle Length				
Markton	7	1	–	4	1	1
Black Mesdag	7	3	–	1	1	2
Richland	3	–	–	3	–	–
Cornellian	4	4	–	–	–	–
Monarch	4	2	1	–	–	1
Garton Gray	3	3	–	–	–	–
		Culms Per Plant				
Markton	7	–	1	1	2	3
Black Mesdag	7	2	1	2	1	1
Richland	3	1	1	–	1	–
Cornellian	4	–	–	1	–	3
Monarch	4	–	–	2	1	1
Garton Gray	3	–	–	–	–	3
		Weight Per Plant				
Markton	7	–	–	2	1	4
Black Mesdag	7	1	3	1	1	1
Richland	3	1	–	1	1	–
Cornellian	4	1	–	–	1	2
Monarch	4	–	2	1	1	–
Garton Gray	3	1	–	–	1	1
		Weight of Straw				
Markton	7	–	–	1	2	4
Black Mesdag	7	1	–	3	1	2
Richland	3	1	–	–	2	–
Cornellian	4	1	–	–	1	2
Monarch	4	–	–	2	2	–
Garton Gray	3	1	–	–	1	1
		Weight of Grain				
Markton	7	1	1	1	2	2
Black Mesdag	7	4	1	1	1	–
Richland	3	2	1	–	–	–
Cornellian	4	1	–	1	–	2
Monarch	4	3	1	–	–	–
Garton Gray	3	1	–	1	–	1
		Heading Date				
Markton	7	1	–	–	–	6
Black Mesdag	6	–	–	1	2	3
Richland	3	–	–	–	–	3
Cornellian	4	–	2	1	–	1
Monarch	3	–	–	1	1	1
Garton Gray	3	–	2	1	–	–

NUMBER OF CULMS

Increased tillering or number of culms per plant is a characteristic often attributed to hybrid plants. Of the 21 crosses studied, 14 had fewer culms than the mean number in their parent strains. The mean decrease in number of culms for the 21 hybrids compared with the parents was 1.138 culms, or 11.89%.

In four crosses the hybrid plants had more culms than either parent, but for seven crosses there were fewer culms than for either parent. Hybridization in oats, therefore, does not necessarily increase tillering.

Neither Markton, Cornellian, Monarch, nor Garton Gray gave evidence of contributing factors increasing tillering in the crosses in which they were used. In some crosses involving these varieties a decrease in number of culms actually occurred. Black Mesdag and Richland crosses at least gave no decrease.

TOTAL PLANT WEIGHT

Data on total plant weight are presented in Table 1. The mean total weight of F_1 hybrid plants was less than the mean weight for plants of the parent strains in 10 of 21 crosses. The mean total plant weight for all crosses was less than that of the parents by 2.55 grams. This apparent decrease of 0.11% is negligible.

In five crosses the mean total plant weight of the F_1 plants exceeded that of the heavier parent, and in an equal number of crosses mean total weight was less than that of the lighter parent. As a whole, the data seem to indicate that the plant weight of F_1 individuals more often is intermediate to that of the parent strain plants, and that hybridization usually does not influence greatly total plant weight.

There is no consistent evidence of any relative difference in the ability of any one of the parent varieties to increase plant weight in the hybrid offspring. In no case was the deviation from the mean of the two parents significant in either direction. The total plant weight fell between or below the average weight of both parents more often than not. The only consistent trend was that hybrid plants weighed less than parent strain plants more often than not.

STRAW WEIGHT

Data on straw weight are presented in Table 1. Straw weight was slightly less in the hybrid plants than in plants of their parental strains. The mean difference between hybrid and parent strains was 5.4 grams, or 6.8%. In 9 of the 21 crosses the mean straw yield of the hybrids exceeded that of their parents. In 12 crosses the hybrids gave lower straw yields than the parents. Six of the 21 crosses gave lower straw yields than either parent, 5 crosses gave yields in excess of either parent, and the other 10 crosses gave yields ranging between their parents in weight. Hybridization, apparently, does not influence straw yield to any greater degree than it affects total plant yield, the two being closely related.

There is no evidence of any definite difference between varieties in increasing straw yield in their hybrids. Such evidence as there is indicates that more often than not straw weight of hybrids is less in proportion to total plant weight than that of parents.

GRAIN YIELD

Data on grain yield are presented in Table 1. The mean average grain yield of the F_1 hybrid plants was greater by 3.2 grams, or 19.6%, than that of their parental strains Fifteen of the 21 crosses yielded more and 5 yielded less than the mean of the parental strains. One cross yielded the same as the parental mean. In eight crosses the average yield of the F_1 hybrids exceeded the mean yield of either parent. In 13 crosses the yield of the hybrid was between those of the parents, although in several cases the yield of the hybrid approached that of the heavier yielding parent. One of the most positive evidences of increased vigor due to hybridization in oats is increased yield of grain. This is noteworthy in the absence of any increase in total plant weight, and in decreases, if any noticeable changes are evident, in straw yield and in number of culms per plant. This seems to indicate either more kernels per panicle or heavier individual kernels. This should be studied further. Increase in grain yield seems to be at the expense of straw yield.

Markton, Cornellian, and Garton Gray do not seem to produce progeny better in yield than these varieties. Hybrids of Monarch, Black Mesdag, and Richland did seem to show a definite increase in grain yield. Markton and Cornellian especially seem to possess most of the factors conducive to grain yield under conditions at Aberdeen, and as the varieties with which they were crossed added no others of importance, no increase above the yield of these varieties should be expected. Where they are adapted these varieties are exceptional yielders.

DATE OF HEADING

It has been observed by the junior author that time of seeding has a marked influence on the relative heading dates of different oat varieties. Of two varieties sown on different dates, one might head first from the first seeding, while the other might head first from a later seeding. Statements relative to heading date must be qualified with direct reference to the conditions under which the experiments were conducted. Data on date of heading of hybrid plants and their parents are given in Tables 1 and 2.

Of the 20 crosses on which data are available, only 4 headed at a later date than the mean heading date of their parental strains. The mean average heading date of these hybrids was 2.16 days earlier than for their parental strains. Sixteen of the crosses headed earlier than the mean heading date of their parent strains, and only four at a later date. In 11 crosses the hybrids reached the heading stage prior to either parent. In only one cross was the hybrid later in heading than both parents. In general, the hybrids grown reached the heading stage earlier than their parents. Earliness usually was characteristic of most of the F_1 progenies of most parents included in these experiments. Very late maturing parents, such as Garton Gray, however, seem to influence their progeny to a degree that the F_1 does not show the earliness characteristic of those of other parents.

HYBRID VIGOR IN THE F_2 GENERATION

Hybrid vigor was studied in F_2 generation plants of one cross in 1927, and of three crosses in 1928. All characters studied in the F_1, except heading date, were studied in 1927, but grain yield only was studied in 1928.

In studying the F_2 generation of the cross Madrid x Wisconsin Wonder in 1927, it was observed that the one row of Madrid averaged 77, that of Wisconsin Wonder 87, and the five rows of the hybrid 83.2 plants per rod row. All were sown at the same seeding rate. In plant size Madrid averaged as follows: Culm height, 127.2 cm; panicle length, 25.9 cm; culms per plant, 5.5; and total plant weight, 30.6 grams, of which straw weight was 21.9 grams and grain weight 8.7 grams. Wisconsin Wonder produced plants averaging as follows: Culm height, 136.6 cm; panicle length, 24.6 cm; culms per plant, 5.6; and total plant weight, 25.0 grams with straw and grain yields of 18.0 and 7.0 grams, respectively. Compared with the mean of the two parents the hybrid plants were 0.77 cm, or 0.59%, shorter; bore panicles 0.45 cm, or 1.71%, longer; had 0.08, or 1.44%, more culms per plant; averaged 3.24 grams, or 11.66%, higher in total plant weight; 2.29 grams, or 11.48%, lower in straw yield; and yielded 0.95 gram, or 12.10%, less grain. Little or no hybrid vigor is indicated.

DATA FOR 1928

In 1928, three crosses, North Finnish x Black Mesdag, Cornellian x Garton Gray, and Monarch x Black Mesdag, were studied. Data are presented in Table 3.

The number of plants per row of the hybrid populations exceeded the mean number in rows of parent populations by about 5%. This difference was consistent and indicates slightly more vigor in hybrid seed than in that of the parental strains. The heavier weight of F_1 hybrid kernels may explain this difference.

The hybrid rows outyielded the parent strains in all three crosses. The average increase varied from 61.3 to 138.9 grams per row, or from 12.8 to 29.2% in different crosses. The average plant yield of the F_2 hybrids exceeded that of parent strain plants for all crosses. Increases ranged from 0.27 to 1.05 grams, or from 5.3 to 19.6%.

TABLE 3.—*Average and mean number of plants and yield of grain in grams per rod row and per plant of three F_2 generation hybrid populations grown at Aberdeen, Idaho, in 1928, and one grown in 1927, compared with their parental strains.*

Parents and crosses	Hybrid No.	No. of rod rows grown	Average yield, grams	Plants per row, aver. no.	Yield per plant, aver. in grams
North Finnish ♀	X2742	1	560	87.0	6.44
Black Mesdag ♂	X2742	1	393	92.0	4.27
Average			476.5	89.5	5.36
F_2 hybrid	X2742	13	615.4	96.0	6.41
Dev. from parent ave			+138.9	+6.50	+1.05
Per cent			29.2	+7.26	+19.59
Cornellian ♀	X2736	2	475	96.5	4.92
Garton Gray ♂	X2736	1	500	91.0	5.49
Average			487.5	93.8	5.21
F_2 hybrid	X2736	12	581.3	97.0	5.99
Dev. from parent ave.			+93.8	+3.20	+0.78
Per cent			+19.24	+3.41	+14.97
Monarch ♀	X2722	3	548.3	96.3	5.69
Black Mesdag ♂	X2722	3	393.3	88.7	4.43
Average			470.8	92.5	5.06
F_2 hybrid	X2722	13	531.5	99.7	5.33
Dev. from parent ave			+61.3	+7.20	+0.27
Per cent			+12.82	+7.78	+5.34
Madrid ♀	X2610	1	670	77.0	8.70
Wisconsin Wonder ♂	X2610	1	609	87.0	7.00
Average			639.5	82.0	7.85
F_2 hybrid	X2610	5	574.0	83.2	6.90
Dev. from parent ave.			—65.5	+1.20	—0.95
Per cent			—10.24	+1.50	—12.10
Mean deviation:					
Average			+57.1	+4.53	+0.29
Per cent			+11.01	+5.06	+4.94

The average acre yield for the four hybrids was 107.9 bushels; that of the parent strains 97.5 bushels. The mean difference was 10.4 bushels, or 10.7%, in favor of the hybrids. For the different crosses the difference in average yield between hybrids and parent strains was as follows: North Finnish x Black Mesdag, an increase of 26.1

bushels; Cornellian x Garton Gray, an increase of 17.6 bushels; Monarch x Black Mesdag, an increase of 11.4 bushels; and Madrid x Wisconsin Wonder, grown in 1927, a decrease of 12.3 bushels. The data indicate that in crosses exhibiting the phenomenon a fair degree of hybrid vigor is continued into the F_2.

Comparative yield data for F_1 and F_2 populations of three crosses, *viz.*, Black Mesdag x North Finnish, Monarch x Black Mesdag, and Cornellian x Garton Gray, were obtained. These data show a decided decrease in hybrid vigor following the F_1 generation, although there was still considerably greater yield from the hybrids than from the parental strains. In the F_1 generation the first cross averaged 5.8 grams, or 35.8%, per plant above its parents, and in the F_2 generation 1.05 grams, or 19.6%. The average increase of the F_1 generation over that of the F_2 was 16.2%. In the second cross the F_1 plants averaged 5.7 grams, or 26.7%, and the F_2 plants only 0.27 gram, or 5.3%, above their respective parental means. The difference was 21.2% in favor of the F_1 plants. In the third cross the F_1 plants yielded 4.2 grams, or 21.9%, and the F_2 plants 0.78 gram, or 15.0%, more than the mean yields of their parents. The difference was only 6.9% in favor of the F_1 plants. The mean increase of all these crosses was 28.1% in the F_1, or 14.8% per plant more in the F_1 than in the F_2 generation.

DISCUSSION

The results of this study indicate an interrelationship between some of the plant characters not previously fully realized. It long has been recognized among plant breeders that inherently early-maturing types are characterized by reduced plant parts. This probably is partly genetic and partly physiologic in nature.

In this study it has been observed that culm height and grain yield often are increased in F_1 hybrids, and that increased yield may be observed to a lesser degree in the F_2 generation. The increased yield of grain in hybrid oats apparently results from increased weight of kernels. Griffee (3) found that in wheat the kernel weight is increased in F_1 hybrids.

Panicle length in hybrids may or may not be dependent on the panicle length of the parents. It has been rather independent in breeding.

Noll (8) considered that earliness in oat hybrids was dominant to lateness. Presumably bringing together in the hybrid the earliness factors present in both parents often results in F_1 individuals which are earlier than either parent. The data presented herein substantiate Noll's conclusions. The reason for the earliness in the F_1 is not known, unless it be that the maximum number of earliness factors present in the two parents has an opportunity for expression in the F_1 plant.

The number of culms, plant weight, straw yield, and heading date are to a considerable extent interdependent in cereals. Any marked increase in earliness should alter the expression of those characters which are more or less controlled by time of maturity. The results of these experiments conform to this expectation to a considerable degree. Earliness was very pronounced in most crosses. Accompanying this earliness, probably as a result of it, the number of culms per plant was reduced, straw yields often were lowered, and total plant weight on the whole showed little if any increase in most cases. Grain yields were increased considerably in the hybrid populations, and this increase in grain yield normally would be expected to cause increased plant weight. This did not follow as a general rule, however, and is additional evidence of an actual reduction in plant size other than grain yield as an incident of earliness. As a result, it is difficult to determine the relative influence of purely genetic and purely physiologic factors. Characters affected in degree of expression by earliness, etc., such as culm number and total plant weight, apparently are limited in usefulness as valid measures of hybrid vigor by the greater earliness of the hybrid population.

From the standpoint of difference in influence of different parents on their progeny, the results obtained in this experiment apparently indicate that some parent strains contribute much more to the F_1 generation hybrids in the way of growth factors than do others. As a result, when these strains are used as a parent in a hybrid marked increase in vigor often results. The reason for this probably is that these strains contain many growth factors not found in the varieties with which they were crossed. In the F_1 individuals the presence of these factors is evidenced by increased development.

CONCLUSIONS

In a study of hybrid vigor in F_1 oat plants as compared with plants of their parental strains it was observed that:

1. Plant height often was increased to some extent by hybridization.

2. Panicle length was increased in some, but not in all, hybrids. The increase usually was not great.

3. The number of tillers often was decreased in the hybrid plants.

4. Total plant weight was greater in some crosses and less in others than the mean plant weight of the parental strains. The mean of all crosses showed no marked change.

5. Weight of straw was less in some hybrids and more in others than in the parental strains. In proportion to the total plant weight it was more often decreased than increased.

6. Grain yield often was increased in the F_1 hybrid plants. The increase on an average was nearly 20%. In the F_2 generation of some crosses a marked increase in yield was noted.

7. Apparently, hybrid kernels were heavier and produced more vigorous plants than kernels from plants of the parental strains.

8. Hybrid progeny most often were earlier in heading than plants of their parent strains.

9. Due to the earliness of F_1 hybrid plants the characters "culms per plant" and "total plant weight" seemed of little value as measures of hybrid vigor.

10. Some oat strains when used as parents apparently influence their hybrid progeny more markedly than do others.

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STERILITY IN RICE HYBRIDS[1]

Jenkin W. Jones[2]

There are hundreds of locally-adapted rice varieties in the principal rice-producing countries of the world. The numerous varieties of this crop probably came into existence in three ways, *viz.*, by natural crossing, by mutation, and by the selection and preservation of desirable forms by man. Some rice varieties yield and mill well, whereas others are of low yielding capacity and of poor quality.

CYTOLOGICAL STUDIES

Kuwada (1)[3] counted the chromosomes in pollen mother-cells of common (*Oryza utilissima* Kcke.) and glutinous (*Oryza glutinosa*, Lour.) rice varieties and found that the haploid number is 12 in both groups.

Nakatomi (2) made a cytological study of the chromosome number in the pollen mother-cells of 21 races and mutations of foreign and domestic rices and his results also show that the haploid number is 12. The size of the chromosomes varied in different varieties. Rau (3), in a cytological study of the root-tips of two domestic (South India) rice varieties and one variety from Madras, found that the somatic chromosome number is 24. He observed that there were three small, four intermediate, and five large chromosome pairs in the cells of the root-tips. The large chromosomes were about twice as long as the short ones.

These cytological studies of rice indicate that probably all cultivated varieties have 24 chromosomes in the somatic cells.

STERILITY IN RICE CROSSES

During the past two decades many papers have been published dealing with the mode of inheritance of various characters in rice crosses. The genetic studies often are by-products of general rice improvement programs in which hybridization is used.

In the rather extensive studies on rice hybridization, which have been conducted in recent years in the various rice-producing countries only one paper is known to the writer in which a marked degree of sterility in the hybrids is reported.

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication April 26, 1930.

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[3] Reference by number is to "Literature Cited," p. 867.

Kato, *et al.* (4) on the basis of morphological differences in rice varieties and sterility in crosses between certain varieties, conclude that the cultivated varieties of rice may be placed in two groups, designated as "Japonica" and "Indica." Varieties of both groups and crosses of varieties within each group exhibit a high degree of fertility, whereas crosses between varieties of the "Japonica" and "Indica" groups show a marked degree of sterility. They found that pollen formation, in hybrids between varieties of the two groups, was abnormal and that a high percentage of the pollen grains was nonfunctional.

In F_2 generations the progeny from crosses of varieties within each group showed normal fertility, whereas in the progeny from crosses between varieties of the two groups the percentage of sterility was high, although it varied materially. Kato and others conclude that the morphological differences present in the varieties of the two groups and the sterility observed in crosses between them indicate that they may be considered as being only distantly related in descent.

The cultivated rices of the "Japonica" group are believed to be native to Japan (proper), Korea, and North China, and those of the "Indica" group apparently are native to Formosa, Southern China, India, and Java. In Central China, while most of the cultivated rices belong to the "Indica" group, some varieties belonging to the "Japonica" group also are found.

MATERIAL AND RESULTS

Varieties of rice belonging to these two groups were used in the experiments reported in this paper, as follows: "Japonica" group, hereafter referred to as "Japanese varieties"—Caloro, Wataribune, Colusa, Bungo, and Aikoku; "Indica" group, hereafter referred to as "Chinese varieties"—C. I. 7022, C. I. 7075, C. I. 7078, C. I. 7389, C. I. 5315, and probably red rice.[4]

In 1924, the crosses Caloro x C. I. 5315 and Wataribune x red rice were made at the Biggs Rice Field Station. The F_1 plants were grown in 1925, but failed to set or mature seed. The writer was absent from the station in the fall of 1925 and no notes were taken on the character of the F_1 plants, except that they failed to set or mature seed.

In 1926, the crosses Caloro x C. I. 5315 and Caloro x red rice were made. Caloro was used as the female parent in both crosses in 1926 replacing Wataribune in the cross with red rice. The F_1 plants of both crosses, consisting of 8 and 10 plants respectively, were grown in 1927 in rows spaced 2 feet apart, with the plants spaced 1 foot apart in the rows.

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[4] C. I. refers to accession number of the Office of Cereal Crops and Diseases, formerly the Office of Cereal Investigations.

The F_1 plants were vigorous and in morphological characters more like the male parents than the female parent. In growth habit the F_1 plants were more spreading, produced more culms, had wider leaves, and the panicles were less dense than for the Caloro variety. One of the F_1 plants produced 56 culms and all tillered freely. On September 30 some of the main culms of the F_1 plants had reached the booting stage. On November 3 panicles were partly exserted from the sheaths, but no seed was set on any of the F_1 plants, although Caloro, the latest maturing parent in both crosses, was fully matured on October 8. The stigmas appeared to be normally developed in the hybrid spikelets; the pollen, however, was poorly developed and apparently nonfunctional. The spikelets bloomed normally, but little or no pollen was found on the stigmas, and, due to lack of fertilization, the glumes did not interlock after blooming.

In November, 1927, before frost occurred, one F_1 plant of each cross was dug up, and these were placed in galvanized buckets. The two F_1 plants were then grown until spring by J E. Morrow in a greenhouse of the U. S. Plant Introduction Garden at Chico, Calif. In the greenhouse both plants produced many culms which headed and bloomed during the winter months, but none of the spikelets set seed. In May, 1928, the two F_1 plants were returned to the Biggs Rice Field Station. Each plant was divided into five parts, and, after the tops had been cut off, the plants were transplanted in the rice nursery. They soon became established in the nursery and began to head and bloom in June, before the earliest varieties in the nursery had reached the heading stage. In July both hybrids matured seed, and, although both showed a high degree of sterility, enough matured seed was obtained for adequate F_2 progenies. The F_1 plants of the cross Caloro x red rice showed less sterility than those of Caloro x C. I. 5315. The matured seed of F_1 plants of the cross Caloro x red rice had red seed coats like the male parent.

In the fall of 1927 four crosses were made between the Chinese varieties C. I. 7022, C. I. 7075, C. I. 7078, and C. I. 7389, which were collected in China in 1925, as female parents, and the Japanese varieties Caloro and Colusa as male parents. These crosses are listed in Table 1 and the dates of first heading, first ripening, and ripening of the parent varieties and the F_1 plants are given. Data on two crosses, Bungo x Caloro and Colusa x Aikoku, in which both parents are Japanese varieties, are also included in Table 1. The data presented for the crosses Caloro x red rice and Caloro x C. I. 5315 are for the year 1927; for all other varieties and crosses the data are for the year 1928. All F_1 plants in crosses between Chinese and Japanese varieties were as late as or later than the latest parent. In only one cross between a Chinese and a Japanese variety, C. I. 7075 x Colusa, did the F_1 plants reach full maturity, whereas in the crosses, Bungo x Caloro and Colusa x Aikoku, in which both parents are Japanese varieties, the F_1 plants behaved in a normal manner. In date of maturity the F_1 plants from the cross Bungo x Caloro were intermediate, whereas in the cross Colusa x Aikoku, both early maturing varieties, the F_1 plants were nearly three weeks later than either parent. F_1 plants which are as late as or later than the latest parent are by no means unusual in rice crosses grown at Biggs.

TABLE 1.—*Average dates of first heading, first ripening, and ripening of the parent varieties and the F_1 plants of eight rice crosses grown at Biggs, Calif., in 1928.*

Parents and F_1 plants	First headed	First ripe	Ripe
C. I. 7022	Aug. 28	Sept. 28	Did not fully mature
Caloro	Aug. 18	Sept. 13	Oct. 5
F_1 plants	Aug. 25	Sept. 24	Did not fully mature
C. I. 7075	Aug. 12	Sept. 6	Sept. 26
Colusa	Aug. 8	Aug. 30	Sept. 19
F_1 plants	Aug. 12	Sept. 6	Sept. 26
C. I. 7389	Aug. 16	Sept. 4	Sept. 21
Caloro	Aug. 18	Sept. 13	Oct. 5
F_1 plants	Sept. 19	Late October	Did not fully mature
C. I. 7078	Aug. 11	Aug. 29	Sept. 18
Caloro	Aug. 18	Sept. 13	Oct. 5
F_1 plants	Sept. 11	Late October	Did not fully mature
Caloro	Aug. 25	Sept. 18	Oct. 8
Red rice	Aug. 29	Sept. 13	Oct. 1
F_1 plants*	Oct. 10	——	Partly headed but no seed set or matured
Caloro	Aug. 25	Sept. 18	Oct. 8
C. I. 5315	Aug. 19	Sept. 8	Oct. 1
F_1 plants*	Oct. 14	——	Partly headed but no seed set or matured
Bungo	July 30	Aug. 23	Sept. 6
Caloro	Aug. 18	Sept. 13	Oct. 5
F_1 plants	Aug. 12	Sept. 4	Sept. 18
Colusa	Aug. 8	Aug. 30	Sept. 19
Aikoku	Aug. 13	Sept. 4	Sept. 20
F_1 plants	Aug. 27	Sept. 25	Oct. 12

*The data given in Table 1 for the F_1 plants and parents for the crosses Caloro x red rice and Caloro x C. I. 5315 are for 1927.

In Table 2 is shown the percentage of sterility for the parent varieties and the F_1 plants grown in 1928, and the F_2 plants grown in 1929. The percentage of sterility was determined from counts of all filled and blank spikelets on 10 panicles, selected at random, of each parent and each F_1 progeny, except for the crosses Caloro x C. I. 5315 and Caloro x red rice, in which the counts were made on 6 and 5 F_1 panicles, respectively. The percentage of sterility in the F_2 plants was determined by counting all filled and blank spikelets on the main panicles from 10 to 63 random plants of each cross. Plants which were likely to be sterile as a result of late maturity were not used in these counts.

TABLE 2.—*Average percentage of sterility in the parent varieties and the F_1 plants grown in 1928, and the F_2 plants grown in 1929, of eight rice crosses at Biggs, Calif.*

Female parent	Percentage of sterility	Male parent	Percentage of sterility	Percentage of sterility F_1 plants	Percentage of sterility F_2 plants
C. I. 7022	6.22	Caloro	2.06	52.61	19.84
C. I. 7075	6.86	Colusa	2.97	70.39	34.56
C. I. 7389	7.93	Caloro	2.06	61.72	26.98
C. I. 7078	5.38	Caloro	2.06	61.75	40.98
Caloro. . . .	2.15	C. I. 5315	9.61	83.61	39.88
Caloro. . . .	2.06	Red rice	5.32	28.89	48.56
Average. . .	5.10	— —	4.01	59.83	35.13
Bungo. . .	5.77	Caloro	2.06	3.63	4.72
Colusa. . .	2.97	Aikoku	5.12	3.16	2.89
Average	4.37	—	3.59	3.40	3.31

The sterility in the parent varieties ranged from 2.06% for Caloro to 9.61% for C. I. 5315. The F_1 plants of crosses between Chinese and Japanese varieties ranged in sterility from 28.89% for the cross Caloro x red rice to 83.61% for the cross Caloro x C. I. 5315. All F_1 plants in which red rice and the Chinese varieties were used as parents exhibited a comparatively high percentage of sterility, whereas the F_1 plants from the crosses Bungo x Caloro and Caloro x Aikoku, all Japanese varieties, were fully as fertile as the parent varieties. Crosses between Chinese varieties should be as fertile as the parents, and Kato, *et al.* (4) state that they were. We have no information bearing on this subject, however.

In the F_2 plants from the crosses under consideration, in which one parent was a Chinese variety or red rice, the average percentage of sterility ranged from 19.84 in the cross C. I. 7022 x Caloro to 48.56 in the cross Caloro x red rice, and the average for all five crosses was 35.13%. The F_2 plants from the crosses Bungo x Caloro and Colusa x Aikoku were equally as fertile as the F_1 and the parent plants.

In Table 3 is shown the number of random F_2 plants from each cross in which all spikelets on the main panicles were counted, the range in the percentage of fertility, and the numbers of F_2 plants in each cross that matured seed, that headed but failed to mature seed, and that failed to head.

TABLE 3.—*Range in percentage of fertility of F_2 plants and the number of F_2 plants that matured seed, that headed but failed to mature seed, and that failed to head, of eight rice crosses grown at Biggs, Calif., in 1929.*

Cross	No. of panicles counted*	Range in percentage of fertility of F_2 plants Low		F_2 plants Matured		With green panicles		Failing to head	
		Low %	High %	No.	%	No.	%	No.	%
C. I. 7022 x Caloro.....	25	21.95	100.00	508	92.4	42	7.6	0	0.0
C. I. 7075 x Colusa ..	40	5.56	96.72	618	99.7	2	0.3	0	0.0
C. I. 7389 x Caloro	10	56.84	92.86	358	72.6	123	25.0	12	2.4
C. I. 7078 x Caloro . .	63	53.33	97.01	473	89.2	57	10.8	0	0.0
Caloro x red rice....	11	10.35	93.33	216	38.4	240	42.7	106	18.9
Caloro x C. I. 5315....	11	12.20	91.46	50	22.8	74	33.6	96	43.6
Bungo x Caloro .	10	89.74	100.00	All	100.00	None	0.0	None	0.0
Colusa x Aikoku.......	10	93.10	100.00	All	100.00	None	0.0	None	0.0

*The number of spikelets per panicle ranged from 40 to 259.

The minimum range in fertility varied from 5.56 to 56.84% in the crosses C. I. 7075 x Colusa and C. I. 7389 x Caloro, respectively. The maximum range in fertility varied from 96.86 to 100% in the crosses C. I. 7389 x Caloro and C. I. 7022 x Caloro, respectively.

In the crosses Bungo x Caloro and Colusa x Aikoku, Japanese varieties, the minimum and maximum range in fertility was from 89.74 to 100% Some of the F_2 plants from crosses between the Japanese and Chinese varieties were as fertile, or nearly as fertile, as the parent varieties and such results are expected.

In the F_2 plants of the cross Caloro x C. I. 5315 only 22.8% of the plants matured seed, while in the cross C. I. 7075 x Colusa 99.7% matured seed. The percentage of F_2 plants that did not fully head and failed to mature seed ranged from 0.3 for the cross C. I. 7075 x Colusa to 42.7% for the cross Caloro x red rice. The percentage of F_2 plants that failed to head ranged from 2.4 in the cross C. I. 7389 x Caloro to 43.6% for the cross Caloro x C. I. 5315.

DISCUSSION

The cytological studies on rice, which were reviewed earlier in this paper, indicate that probably all cultivated varieties of rice have the same number of chromosomes. Likewise, all cultivated rice varieties (*Oryza sativa*) usually are considered as belonging to a single species. It seems logical to expect, therefore, that in rice crosses the hybrids should be as fertile as the parent varieties. Rau (3) states that, "there has not been so far any reported case in which difficulty was experienced in crossing or sterility was observed in the offspring in the very extensive series of crossing-experiments to which different varieties of this plant (rice) have been subjected." He evidently had not seen the paper by Kato, *et al.* (4) when this statement was made.

The data presented in this paper concerning the behavior of F_1 and F_2 plants from crosses between Japanese and Chinese rice varieties show that there is a marked degree of sterility in the offspring from these crosses. In addition to the sterility observed the development of the plants was abnormal, as is shown by the large number of F_2 plants which were so late that they failed to head and of those which headed but failed to mature seed.

The characteristic late maturity or failure to mature fully in the F_1 plants and the failure of many F_2 plants even to reach the heading stage, in the crosses under consideration, is certainly unusual in varietal crosses. This abnormal behavior may be due in part to the action of genetic factors for late maturity, some of which entered the crosses from both parents. However, if factors for late maturity were present in the parent varieties they were recessive to factors for earliness, for none of the parental varieties are really late-maturing rices. It seems more reasonable, therefore, to assume that the sterility and lateness observed in the F_1 and F_2 plants are probably due to incompatibility in the chromosome mechanism which prevented normal functioning and development of the hybrid plants.

CONCLUSION

The results presented in this paper tend to support the idea advanced by Kato and others that the cultivated varieties of rice belong to two types, "Japonica" and "Indica," which are only distantly related in descent.

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ROOT SYSTEMS OF YOUNG CORN PLANTS IN RELATION TO FERTILIZER APPLICATIONS[1]

C. E. MILLAR[2]

Much interest is being manifested in the location of fertilizer dropped near the seed kernel of corn in order that the young plant may derive early benefit from the nutrients supplied without danger of damage to the seedling. As a preliminary to the investigation of the problem, a knowledge of the extent and character of the root system of young corn is essential. Unfortunately, few data on the subject are found in the literature which has come to the writter's attention.

Hay's[3] discussed the development of the root system of very young corn but gave no data as to location in the soil and extent of the roots. King[4] made a limited number of studies of corn roots nine days after planting by burying disks of fine meshed wire netting at intervals of 2 inches to a depth of 18 inches before planting. After the period of growth the set of disks was dug out and the soil removed from the root system by a stream of water. The detailed studies of Weaver[5] give an admirable picture of the root systems of corn for various periods, but unfortunately his investigations did not begin until the plants were five weeks old and had approximately eight leaves.

A knowledge of the root system of corn in the early stages of growth is also of value in determining suitable tillage practices.

PLAN OF STUDIES

The original plan was to determine the depth of roots found near the surface at various distances from the plant and it was not until the work was well under way that the desirability of making a detailed study of the entire root system became evident. As a result, the major portion of the work on sandy loam did not include the total root system of the plants.

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[1] Contribution from Soils Section, Michigan Agricultural Experiment Station, East Lansing, Mich., as Journal article No. 38 (N. S.). Received for publication May 1, 1930.

[2] Professor.

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[4] KING, F. H. Natural distribution of roots in field soil. Wis. Agr. Exp. Sta. Rpt., 1892: 112-120. 1893.

[5] WEAVER, J. E. Root Development of Field crops. New York: McGraw-Hill Book Co. 1926.

Measurements were begun when the plants were quite small having only two well developed leaves. As the erectness of the leaves varied in different plants the total height with the leaves stretched upward was adopted as a uniform method of measuring height. The major portion of the studies were made when the total heights of the plants were from 8 to 10 inches, although some data were collected on smaller plants. At this stage of growth the plants were found to have two whorls of roots. When the plants on sandy loam had a total height of 23 to 25 inches some further studies were made, but a cultivation with shovel cultivators so damaged the roots that the work could not be extended on the other soil types.

The studies were made on four soil types varying greatly in physical characteristics of their profiles. The types used were Rifle muck, Granby sandy loam, Coloma loamy sand, and Conover loam.

RESULTS OF STUDIES

The depths of the roots were measured at 3-inch intervals from the plants. The data were compiled by averaging the measurements for the roots of each plant. The number of roots measured in the case of each plant is indicated by the figure to the right of the dash following the average depth recorded. Thus in Table 1, it is seen that two roots from plant No. 1 had an average depth of 2.43 inches at a distance of 3 inches from the plant. The average of these averages was then computed.

The data for plants growing on sandy loam are found in Table 1 and those for plants in Conover loam in Table 2. In the studies of plants growing on the other two soil types, data were collected for both the upper and lower whorl of roots. The results on Coloma sand are found in Table 3 and those for muck in Table 4.

TABLE 1.– *Average of root measurements on Granby sandy loam.*

Plant No.	Total height, inches	Depth of roots in inches at designated distances from plant			
		3 inches	6 inches	9 inches	12 inches
1	8.00	2.43–2	2.75 2	3.62–1	——
2	8.00	2.06–2	2.68–2	3.62–2	——
3	9.50	2.12–3	3.04 3	3.88–1	——
4	9.50	2.25–1	2.63–1	2.75–1	——
5	8.25	2.25–2	3.62–2	——	——
6	8.00	2.25–2	3.50–1	——	——
7	9.75	1.75–1	2.88–1	3.75–1	——
8	10.00	2.00–2	2.62–2	——	——
9	10.00	1.93–2	2.50–2	4.00–2	5.00–1
Average	9.00	2.12	2.91	3.60	5.00

TABLE 2.—*Average of root measurements on Conover loam.*

Plant No.	Total height, inches	Depth of roots in inches at designated distances from plant 3 inches	6 inches	9 inches
1	8.25	2.50-3	3.00-2	4.00-1
2	9.00	2.66-4	3.75-4	5.50-1
3	8.12	2.94-4	3.75-2	6.00-1
4	8.50	2.33-3	3.75-2	4.00-1
5	8.25	2.87-2	4.00-2	——
6	8.00	2.87-2	——	——
'erage	8.35	2.69	3.65	4.87

TABLE 3.—*Average of root measurements on Coloma loamy sand.*

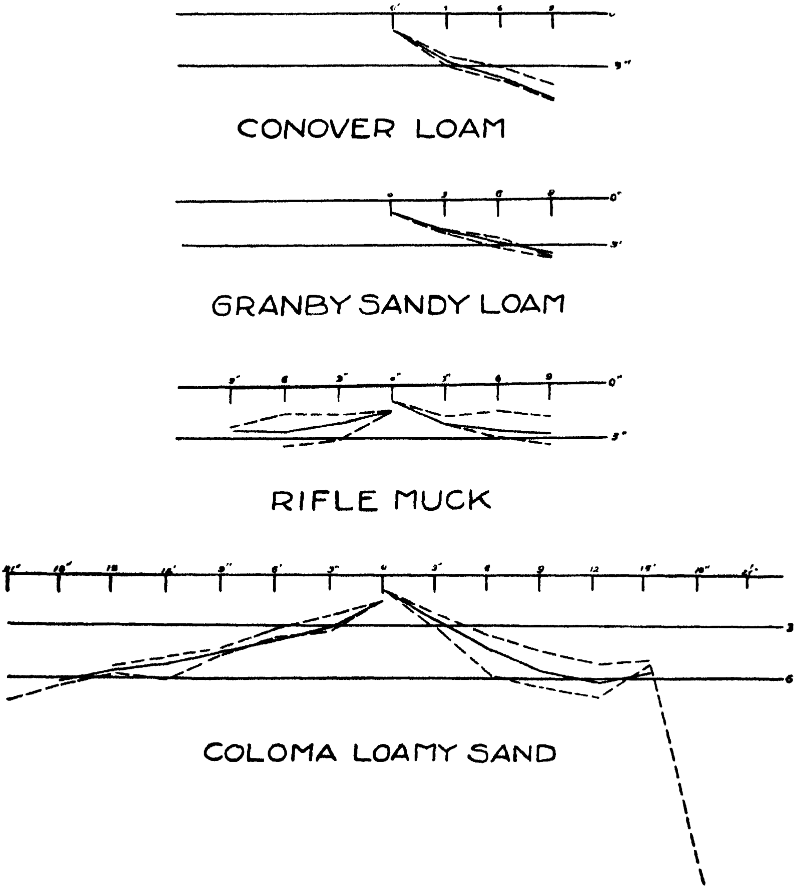
Plant No.	Total height, inches	Depth of roots in inches at designated distances from plant 3 inches	6 inches	9 inches	12 inches	15 inches	18 inches	21 inches
				Upper Whorl of Roots				
1	9.63	2.50-3	4.08-3	5.50-3	6.25-2	5.25-1	——	——
2	10.00	2.81-4	3.87-4	5.66-4	6.37-2	6.75-1	——	——
3	10.00	3.12-4	5.78-4	6.54-3	7.18-2	5.25-1	18.00-1	——
4	8.75	2.25-4	3.66-4	4.53-4	5.16-4	5.00-1	——	——
5	8.00	2.81-4	4.59-4	6.09-4	6.62-2	——	——	——
6	8.63	2.38-2	3.38-2	5.12-1	5.37-1	5.88-1	7.00-1	7.12-1
7	9.00	3.17-3	4.67-3	6.12-2	——	——	——	——
Average	9.14	2.72	4.29	5.65	6.16	5.62	——	7.12
				Lower Whorl of Roots				
1	9.63	2.37-1	3.25-1	4.37-1	4.88-1	5.50-1	——	——
2	10.00	2.88-2	3.94-2	4.44-2	4.50-1	5.50-1	5.88-1	6.63-1
5	8.00	3.63-2	4.06-2	——	——	——	——	——
6	8.63	3.17-3	3.67-3	4.71-3	6.04-3	5.88-2	6.62-2	7.56-2
Average	9.07	3.01	3.73	4.51	5.14	5.63	6.22	7.09

TABLE 4.—*Average of root measurements on Rifle muck.*

Plant No.	Total height, inches	Depth of roots in inches at designated distances from the plants 3 inches	6 inches	9 inches	12 inches
	Upper Whorl of Roots				
1	8.75	2.10-5	3.06-4	——	——
2	8.00	2.25-5	2.90-5	2.75-2	——
3	9.25	1.84-3	1.50-2	1.84-2	3.75-1
4	8.75	2.25-3	3.06-2	3.50-1	——
5	9.75	2.27-5	2.63-1	——	——
6	9.50	2.78-5	——	——	——
Average	9.00	2.25	2.63	2.69	3.75
	Lower Whorl of Roots*				
1	8.75	1.09-4	2.17-3	2.88-2	3.37-1
2	8.00	1.88-2	1.81-2	2.38-2	3.37-1
3	9.25	2.19-2	——	——	——
4	8.75	2.08-3	2.12-3	2.46-3	3.62-1
5	9.75	2.68-2	3.18-2	2.25-1	——
6	9.50	3.18-2	3.56-2	——	——
Average	9.00	2.18	2.57	2.50	3.45

*These data do not include the first or primary root.

The data are presented graphically in Fig. 1. The solid line to the right represents the average data for the upper whorl of roots of all the plants on each type of soil. The broken lines above and below the solid line represent the average data for the plant having the most shallow and the deepest roots, respectively. In other words the solid line represents the average condition found in each type of soil, while the broken lines present the extremes in depth of roots represented by single plants.


CONOVER LOAM

GRANBY SANDY LOAM

RIFLE MUCK

COLOMA LOAMY SAND

FIG. 1.—A diagramatic presentation of the average of measurements showing the location and extent of the roots of young corn. The lines to the right present data on the upper whorl of roots and those to the left on the lower whorl. The data for each plant was first averaged and then an average of these averages found. The solid line in each case represents this final average. The broken lines present the averages for the plants having the most shallow and the deepest roots, respectively.

The lines to the left present similar data for the lower whorl of roots. In as much as very little data for the lower roots of plants on the sandy loam and loam soils were collected, the graphs in these cases have no left portion.

It was found that the first or primary root extended almost straight downward from the seed for a short distance and then curved sharply and grew in an almost horizontal direction. This root is shown by the heavy dot and dash line in the graphs.

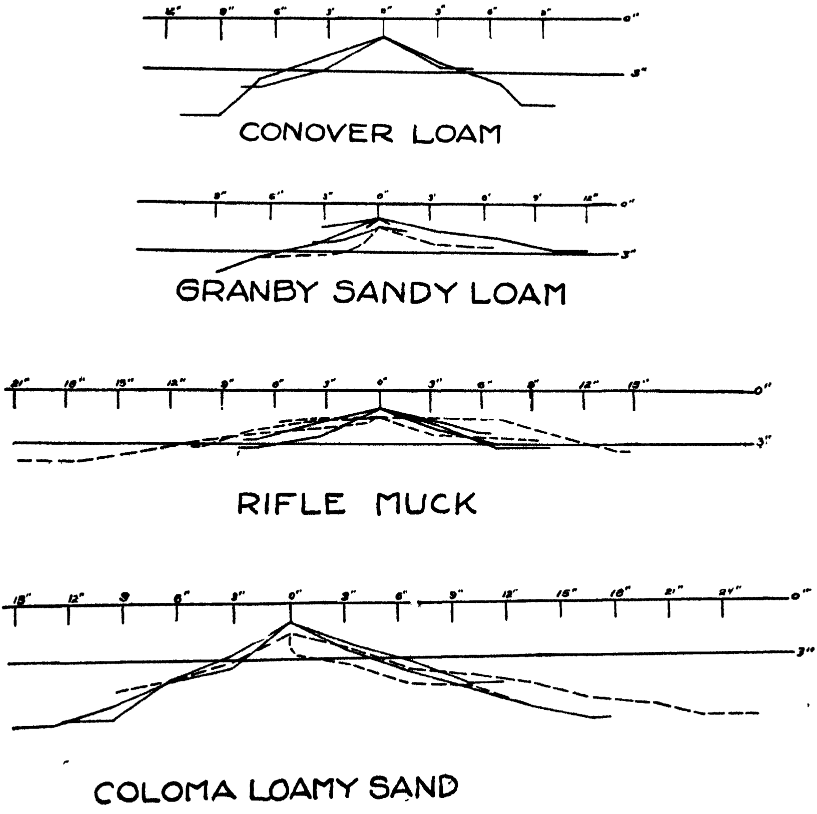


FIG. 2.—These graphs present the root systems of individual plants. Solid lines are used for the upper whorl of roots and broken lines for the lower whorl.

In Fig. 2 are shown typical root systems of individual plants on the different types of soil. It will be noted that only the surface roots are shown for the plant growing on loam soil, in as much as the heavy texture of the soil made accurate studies of the location of the entire root system impractical. The smaller root growth in the sandy loam is due in part at least to the fact that this plant was somewhat smaller than those growing in the other soils.

It is surprising to note that in Conover loam the roots strike downward at a much greater angle than in sandy loam or muck. The writer is inclined to think that this result is due to seedbed condition as the loam was not so finely granular but, on the other hand, was somewhat cloddy.

In the Coloma sand the roots not only penetrate the soil at a greater angle than in muck and sandy loam, but have attained a much greater length than in any of the other soils. This greater ramification in drier and more friable soils is a rather general observation in root studies.

The roots as a whole were devoid of branches and appeared very white and succulent. The much branched condition reported by Weaver must develop at a somewhat later period of growth. The primary or first root which extends directly downward and then horizontally is an exception in that it was literally covered with short lateral extensions.

DISCUSSION

The studies show the general tendency of corn roots to develop horizontally in the early stages of growth and to remain at comparatively shallow depths. At a distance of 6 inches from the plant the average roots of the upper whorl in sandy loam and muck were within 3 inches of the surface. In the case of the loam the average root was less than 4 inches from the surface at a point 6 inches from the plant, while in sand the average depth was about 4½ inches. As a whole, the roots in the lower whorls are little, if any, deeper than those of the upper whorl.

Nine inches from the plant the roots from both the upper and lower whorl were within 5 inches of the surface in sandy soil and about 3 inches in muck. The upper roots in sandy loam and loam average less than 4 inches and 5 inches, respectively, from the surface at the 9-inch point.

It is evident from these data that fertilizer placed on either side of the seed and slightly below it will be in the direct line of growth of the roots and should therefore be used by the plant earlier than fertilizer placed directly below or above the seed. The writer and Prof. E. C. Sauve of the Agricultural Engineering Department are cooperating in an endeavor to devise an attachment to the corn planter which will drop the fertilizer in this position.

THE DETERMINATION OF THE READILY AVAILABLE PHOSPHORUS OF SOILS[1]

EMIL TRUOG[2]

The determination of the readily available phosphorus of soils is a problem that has been under consideration and investigation by soil chemists for many years and naturally an extensive literature pertaining thereto now exists. Those interested in a review of the literature are referred to the reports of Russell and Prescott (5),[3] McGeorge (3), and Shedd (6).

The N/5 nitric acid method, developed in this country largely by Peter and Averitt (4), by Stoddart (7), and by Fraps (2), and the 1% citric acid method, developed in England by Dyer (1), have probably been the most successful of the methods proposed. Until recently, investigators have been handicapped in working on this problem by a lack of a satisfactory method for determining small amounts of phosphorus quickly and accurately. The development of the Denigès colorimetric method for phosphorus in recent years has entirely eliminated this handicap. The perfected method is, undoubtedly, one of the most satisfactory colorimetric methods in existence. For a detailed discussion of this method the reader is referred to the paper by Truog and Meyer (8).

STRENGTH OF SOLVENT EMPLOYED

For the extraction of the readily available phosphorus of soils, it would appear desirable, if possible and practicable, to use a solvent which is approximately the same strength as the one operating in plant feeding. The evidence at hand indicates that the solvent operating at the points of contact between root hairs and soil particles is a saturated solution of carbonic acid. This solution has a normality slightly greater than one twenty-fifth and a pH of 3.7 or thereabouts. In an attempt to approximate this solvent in a practical and convenient way, the writer selected a 0.05N sulfuric acid solution buffered with ammonium sulfate to a pH of 3. On a quantitative basis, the saturated carbonic acid solution is about 20 times as strong as the latter solvent; on an intensity basis, the latter solvent is a little more than 4 times as strong as the carbonic acid solution.

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[1] Paper read as a part of the symposium on "Phosphorus" at the meeting of the Society held in Chicago, Ill., Nov. 14, 1929. Contribution from Dept. of Soils, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station.

[2] Professor of Soils.

[3] Reference by number is to "Literature Cited," p. 882.

On the basis of what has just been stated, the intensity of the solvent selected may appear too high, but it should be remembered that quantity and intensity compensate each other to some extent. Moreover, the intensity of the solvent usually decreases some during the extraction process as it comes in contact with the soil, due to the solution of bases, while in the case of plant feeding the solvent is continually being recharged by the excretion of additional carbonic acid by the root hairs. At any rate, the solvent selected has an intensity which is not greatly at variance with that found in extremely acid soils and hence it probably exerts no profoundly unnatural action on soils.

It is to be noted further that a considerable increase in the strength of the solvent would cause the solution of sufficient iron and organic matter, in many cases, to interfere seriously with the subsequent direct, colorimetric, determination of the phosphorus. Fortunately, a strength of solvent such as proposed does not introduce these complications.

Buffering a solution is desirable from two standpoints: First, it makes possible a solvent of not too great an intensity, and still one of sufficient capacity so that it will not be reduced in strength too seriously by the presence in soils of readily available bases, especially such as exist as carbonates and in easily replaceable form. Second, the salt, added as a buffer, flocculates the soil and greatly aids filtration and assures the securing of a perfectly clear extract.

RATIO OF SOLVENT TO SOIL

For several reasons it is desirable to use a high ratio of solvent to soil in the extraction process. A high ratio probably lessens refixation of dissolved phosphates because the concentration in solution is kept proportionately low. It also makes possible the maintenance of a more constant strength of solvent. Furthermore, the high ratio makes it possible to imitate plant feeding more closely in the extraction process, in that the soluble portion is removed from the field of action to a greater extent than with a lower ratio. The extent of the ratio which it is practicable to use is limited largely by the analytical procedure at hand. With the employment of the Denigès colorimetric method, the writer found it convenient to use a ratio of 200 of solvent to 1 of soil. With this ratio the concentration of phosphate in the extract is usually such that the reagents may be added directly and the color developed without further evaporation or dilution.

PERIOD OF EXTRACTION

The solution of readily available phosphates proceeds rapidly in the solvent employed. It is especially rapid during the first few minutes of extraction, in which time the greater portion of the readily available phosphorus may be dissolved. At the end of 30 minutes the action usually slows up greatly and it may be assumed that practically all of the readily available phosphorus has been dissolved, excepting in the cases of soils with high amounts. However, these cases do not lead to confusion since soils with high amounts give up in 30 minutes sufficient amounts of phosphorus so that they are correctly placed in the proper class as regards amount of readily available phosphorus. In case it is desirable to know the total amount of readily available phosphorus in these soils, they may be extracted for a longer time and even re-extracted if necessary. Some of our data indicate that with certain soils refixation sets in after a three- or four-hour period of extraction. Filtration and re-extraction is advisable, therefore, if the period of extraction is prolonged beyond three or four hours. Continuous extraction on a filter and funnel may be best when it is desired to extract all of the readily available phosphorus from soils containing high amounts.

A short period of extraction is desirable from another standpoint. It makes possible a measurement of rate of solubility of the readily available phosphorus. From a crop feeding standpoint this is probably a matter of considerable importance. It is conceivable that in some soils a portion of the phosphorus may be present in such large particles as to have a rather slow rate of availability to plants and still be completely dissolved with a weak solvent if sufficient time is allowed.

READILY AVAILABLE AND DIFFICULTLY AVAILABLE PHOSPHORUS

Tests with various minerals showed that the 0.002 N sulfuric acid solution buffered to a pH of 3 completely dissolves finely ground rock phosphate in 1 hour and powdered apatite in several hours. Powdered dufrenite gives up only a trace of phosphorus to this solvent, which when calculated as for a sample of soil would probably correspond to about 10 pounds of phosphorus per acre. Recent tests by Ford and the writer lend support to the view that the difficultly soluble phosphorus of many soils actually exists in the form of a basic ferric phosphate analogous to dufrenite. It is important to note that the phosphorus in these difficultly soluble forms still has an appreciable availability and may suffice under certain climatic conditions to produce a fairly satisfactory yield of certain crops. This brings us to the question as to what is meant by available and unavailable phosphorus.

Plants probably secure some phosphorus from even the most difficultly soluble forms found in soils. For this reason the writer prefers to use the designations *readily available* and *difficultly available* in place of available and unavailable in referring to the availability of the different forms of phosphorus found in soils. The writer believes that there is a rather abrupt change in availability between the readily available phosphorus existing as calcium and possibly magnesium phosphates and that tied up with ferric iron in particular, and possibly also aluminum and titanium in difficultly available forms. It should be recognized that even in a short period of extraction for readily available phosphorus, a little phosphorus is always dissolved from the difficultly available forms. The amount coming from these sources may equal 10 or 20 pounds per acre and possibly in some cases even more. This situation, at first thought, might lead one to think that there exists a whole series of phosphates whose solubility gradually merges from the highest to the lowest, while as a matter of fact only two different phosphates may make up the main bulk. The phosphorus existing as calcium phosphate goes into solution very rapidly and its solubility and availability are strikingly greater than the difficultly available forms. On the basis of the data available, the writer believes that in the case of most soils, the readily available phosphorus exists largely as calcium phosphate, while the difficultly available exists largely as basic ferric phosphate. The phosphorus in fresh organic matter should be classed as readily available.

MINIMUM LIMITS OF READILY AVAILABLE PHOSPHORUS WHICH SUFFICE

The question may well be asked, What is the minimum supply of readily available phosphorus that is adequate for crop production? This minimum supply varies depending upon the crop, climate, and soil involved. Crops with a long growing period can get along with a lower supply than those with a shorter growing period, because the long growing period makes possible the utilization of a greater amount of the difficultly available phosphorus. A climate which makes possible a long growing period has a similar effect. As a consequence, fairly good crops of corn can apparently be produced in the South on soils whose readily available phosphorus supply would be entirely inadequate in the North.

McGeorge (3), using 1% citric acid for the extraction of Hawaiian sugar cane soils, finds the minimum limit of readily available phosphorus for good sugar cane production to be approximately 0.004%

of phosphoric acid. This corresponds, approximately, to 35 pounds per acre of phosphorus in the plowed layer. Dyer (1), when he proposed the 1% citric acid method, set the minimum limit at 0.01% of phosphoric acid, which corresponds approximately to 88 pounds of phosphorus per acre in the plowed layer. Stoddart (7), working with the N/5 nitric acid method, set the minimum limit at 0.015% of phosphoric acid, which corresponds to approximately 132 pounds of phosphorus per acre in the plowed layer. It is thus seen that the minimum limit varies, even when the same solvent is used, and depends, at least partially, on the kind of crop grown and climatic conditions involved.

Using 0.002 N sulfuric acid, buffered to a pH of 3 for extraction, according to the method about to be described, the writer has tentatively set the minimum limit of readily available phosphorus, for general farming under Wisconsin conditions, at 75 pounds per acre in the plowed layer for the heavier, better soils, and at 50 pounds for the very sandy soils. The sandy soils, due largely to their inability to supply crops with sufficient moisture, have a lower crop-producing potentiality and hence with them a lower limit of readily available phosphorus suffices. Another factor which may operate in certain sandy soils, as compared to the heavier soils, is the greater accessibility to plants of whatever readily available phosphorus there is present.

Unquestionably, a higher amount of readily available phosphorus than just indicated will further tend to increase yields in many cases. Nitrogen fixation and in fact all favorable biological activities of soils are greatly stimulated by a liberal supply of readily available phosphorus. The economics involved must, however, be taken into consideration. Where land values and crop prices are relatively high, it will be economical to farm with higher amounts of readily available phosphorus than where the reverse conditions hold. In the production of garden, truck, and special crops, it is probably desirable to have 150 pounds or more per acre of readily available phosphorus present.

On the other hand, it is, of course, of no avail to raise the readily available phosphorus supply beyond the point where climatic conditions, such as amount or distribution of rainfall, limit the yield. Because of the various factors involved, it appears that for the growing of corn in certain sections of the South 20 to 30 pounds per acre of readily available phosphorus may suffice.

PROPOSED METHOD FOR DETERMINING READILY AVAILABLE PHOSPHORUS OF SOILS

REAGENTS

Ammonium molybdate-sulfuric acid solution.—Dissolve 25 grams of ammonium molybdate in 200 cc of water heated to 60°C and filter. Dilute 280 cc of arsenic- and phosphorus-free concentrated sulfuric acid (approximately 36 N) to 800 cc. After both solutions have cooled, add the ammonium molybdate solution, slowly with shaking, to the sulfuric acid solution. After the combined solution has cooled to room temperature, dilute with water to exactly 1,000 cc. This is a 10 N sulfuric acid solution containing 2.5 grams of ammonium molybdate per 100 cc.

Stannous chloride solution.—Dissolve 25 grams of $SnCl_2.2H_2O$ in 1,000 cc of dilute (10% by volume) hydrochloric acid solution. Filter if necessary. Store in a bottle with a siphon or side opening near the bottom, arranged with a glass stopcock for delivering the the solution in drops. The solution should be protected from the air by floating a layer of white mineral oil about 5 mm thick over the surface.

Sulfuric acid solution for extraction.—Prepare a stock solution of exactly N/10 sulfuric acid by titrating against standard alkali. Dilute convenient volumes of this to 0.002 N and buffer by adding 3 grams of $(NH_4)_2SO_4$ per liter so as to produce a pH of 3 in the final solution.

Standard phosphate solution.—Dissolve 0.2195 gram of recrystallized potassium-dihydrogen-phosphate and dilute to 1,000 cc. This solution contains 50 p.p.m. of phosphorus and is too concentrated to use directly. A second stock solution is made by taking 50 cc of the first stock solution and diluting to 500 cc. This second stock solution contains 5 p.p.m. and is used for making the standard solution for comparison. To make this standard solution take 5 cc of the stock solution, dilute to 95 cc with distilled water, add 4 cc of the ammonium molybdate-sulfuric acid solution, and mix thoroughly by shaking in an Erlenmeyer flask. Add 6 drops of stannous chloride and shake. Dilute to exactly 100 cc, shake, and the solution is ready for use. It contains 0.25 p.p.m. of phosphorus. For very dilute solutions, use 2 cc of the stock solution, but the same amount of reagents, giving a standard which contains 0.1 p.p.m. of phosphorus. After standing 10 to 12 minutes, the standard starts to fade, and a drop more of stannous chloride should then be added to bring the full color back which will again be permanent for 10 to 12 minutes.

EXTRACTION AND DETERMINATION OF THE READILY AVAILABLE PHOSPHORUS

Extraction and determination.—Place 2 grams of 20-mesh soil and 400 cc of the 0.002 N sulfuric acid in a 750-cc Erlenmeyer flask or other suitable flask or bottle and shake for one-half hour. Filter through S. S. 589 filter paper. Discard filtrate until it comes through *perfectly* clear. Then place 50 cc of the clear filtrate in a 200-cc Erlenmeyer flask, add 2 cc of the ammonium molybdate-sulfuric acid solution, and shake well. Then add 3 drops of the stannous chloride solution, shake, and compare with the standard within a few minutes. In making the color comparison with ordinary Nessler tubes it is convenient to proceed as follows: Place the 52 cc of unknown in a Nessler tube and the standard in a 100-cc cylinder. Now hold the tube with the unknown together with an empty Nessler tube over a white background and pour standard solution from the cylinder into the empty tube until the colors match. Then read the cylinder to ascertain the amount of standard required.

Calculation.—When the comparisons are made as just indicated, the calculation to pounds per acre is very simple. The 52 cc of unknown solution represents 0.25 gram of soil. If the standard contains 0.25 p.p.m. of phosphorus, and if it took, say, 40 cc of standard to match the unknown, the amount of readily available phosphorus in the soil will be equal to $\frac{40}{0.25} \times \frac{0.25}{1}$, or 40 p.p.m. If we are dealing with a silt loam soil which weighs approximately 2,000,000 pounds per acre plowed layer, the readily available phosphorus will be equal to 2 x 40 or 80 pounds per acre. When the concentration of the standard, the amount of unknown, and the readings are taken as suggested, all that is necessary is to multiply the number of cc of standard used by the factor 2, to translate the results into pounds per acre. In the case of sands, the factor 2.5 and in the case of mucks and peats a factor less than 2, as the case may be, should of course be used. When other amounts of unknown and concentrations of standard are used it will be desirable to work out other sets of factors to have at hand.

Important precautions.—It should be noted that arsenic produces exactly the same color as phosphorus, and that reagents, filter paper, and glass often contain appreciable quantities of arsenic. Pyrex glass contains 0.7% arsenic oxide, and the use of new pyrex vessels will cause serious contamination. All glassware should be thoroughly weathered by treatment with warm sulfuric acid-dichromate solution for at least 24 hours. Filter paper may be tested by tearing up a sheet of it and throwing the shreds into a blank test. If a color develops on shaking, the filter paper is, of course, not suitable. It is absolutely essential to run a blank on all chemicals and glassware at frequent intervals. To test the chemicals proceed as follows: Add 4 cc of the ammonium molybdate-sulfuric acid solution to 96 cc of water and after mixing thoroughly add, with shaking, 6 drops of the stannous chloride solution. Compare in Nessler tubes with pure water. If the chemicals are free of arsenic and phosphorus, not more than a very faint blue color is produced. If the standard and unknown solutions are not acid enough, the stannous chloride will reduce the ammonium molybdate and produce a blue color independently of the presence of phosphates. If the acidity is too high, the color due to the presence of phosphate will not be intense enough. It is essential, therefore, that the standard and unknown solutions always contain very nearly the concentrations of acid and molybdate given in the directions. Dilution with water after the color is developed will, of course, change these concentrations and is not permissible.

SUMMARY

It is suggested that the designations *readily available* and *difficultly available* be used rather than available and unavailable in speaking of the phosphorus of the soil in relation to its availability to plants. It is probable that plants secure some phosphorus from even the most difficultly available phosphorus compounds of the soil, and hence it is not correct to speak of the phosphorus in these compounds as unavailable. However, there appear to be two rather distinct groups of phosphorus compounds which are found in varying proportions in different soils and which have widely different degrees of solubility and availability. It appears that in most cases the readily available phosphorus exists largely as calcium phosphate and the difficultly available as basic ferric phosphate.

When a soil is extracted with a weak solvent, the more readily available group dissolves rather quickly, while the other group gives up its phosphorus very slowly. The difficultly available group may furnish enough phosphorus, under certain conditions which make possible a long growing period, to produce a fairly satisfactory crop. Under conditions of more intensive agriculture and shorter growing periods, there must be present a greater supply of the readily available group of phosphorus compounds.

A method is proposed in which a 0.002 N solution of sulfuric acid, buffered with ammonium sulfate to a pH of 3, is used in the proportion of 200 cc of solvent to 1 of soil to extract the readily available

phosphorus of the soil. The soil is agitated in contact with the solvent for 30 minutes. The phosphorus is then determined directly in the filtered extract by means of the Denigès colorimetric method.

For general farming under Wisconsin conditions the minimum limits of readily available phosphorus have been tentatively set at 75 pounds per acre in the plowed layer for the heavier soils and 50 pounds for the lighter sandy soils. Higher amounts are, however, desirable. For garden and special crops this limit should be raised to 150 pounds or possibly higher still. Under other climatic and cropping conditions lower amounts may suffice.

The method is rapid and in hundreds of tests during the past several years has given quite satisfactory results.

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PERSISTENCE OF SOIL DIFFERENCES WITH RESPECT TO PRODUCTIVITY[1]

R. J. GARBER AND M. M. HOOVER[2]

In recent years there has been a tendency among agronomists to inquire more carefully into soil heterogeneity in connection with laying out more or less permanent experiment plats. In most crop rotation or fertilizer studies carried out on field plats the treatment and cropping plan for each plat are determined at the beginning of the experiment and remain the same for a period of years, hence the only opportunity for taking care of natural differences in soil productivity is at the time the plats are located.

In some instances this has been done by more or less systematically repeating the same crop and treatments, i. e., by plat replication. Another device which has been used frequently is the check plat. The checks have been distributed in various ways and several methods have been suggested for making corrections for soil heterogeneity based on the checks. Few field experiments have been planned on areas previously analyzed for soil heterogeneity by determining crop yields. An attempt to do this was reported from the West Virginia[3] Agricultural Experiment Station a few years ago.

In this study two uniformity crops, oats and wheat, were harvested from each of 270 plats of approximately 1/51 of an acre net, and the yields determined. These plats are located on Wheeling fine sandy loam. The correlations between the yields of contiguous plats showed plainly that considerable soil heterogeneity existed on this tract. Moreover, the inter-annual correlation between the yield of oats in 1923 and the yield of wheat in 1924 showed a persistence of differences in productivity between plats.

The persistence of differences in productivity between plats was pointed out by Harris and Scofield[4] in 1920. In this study all the plats were occupied by the same crop and given the same treatment. A question of importance is, will the natural variation in soil productivity among plats as revealed by a crop uniformity test persist

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[2] Head of Department and Assistant Agronomist, respectively.

[3] GARBER, R. J., McILVAINE, T. C., and HOOVER, M. M. A study of soil heterogeneity in experiment plots. Jour. of Agr. Res., 33:255-268. 1926.

[4] HARRIS, J. A., and SCOFIELD, C. S. Permanence of differences in the plots of an experimental field. Jour. Agr. Res., 20:335-356. 1920.

after an experiment has been begun involving different crops and different soil treatments? The criticism has been made that a measurement of soil difference in terms of crop yields is of little value in helping to plan a field experiment because soil heterogeneity as revealed by the crop uniformity test does not persist after the differentials incident to the particular investigation have been introduced. Suppose that phosphorus deficiency is the explanation for variation in soil productivity, then, argue those who belittle the value of a crop uniformity test, treatment with superphosphate will remove the cause of the variation. The fallacy in this argument is that crop yields are rarely, if ever, dependent on one factor.

This paper presents data which have been recorded during the past seven years at the Lakin substation, showing the relation between the yields obtained in the uniformity tests made in 1923 and 1924, and the yields obtained since the rotation experiments were begun in 1925.

THE ROTATION EXPERIMENTS

Thirty-two different cropping plans are being compared in the rotation experiment at the Lakin substation. All plats receive an application of superphosphate at the rate of about 200 pounds per acre per year. Thirty-five plats do not receive lime, while the remainder are treated with lime as needed. During the past five years two uniform applications of lime have been made to all the plats receiving this material.

Three different rotations involve a comparison of livestock versus grain farming. In the former, grain and roughages are fed to or used as bedding for livestock, and the manure is returned to the plats. In the grain system the grain is removed but the crop residues are returned to the plats. Six of the rotations are concerned with comparisons of different cover crops.

There are harvested each year 84 plats of corn, 34 of wheat, 24 of soybeans for seed, 18 of soybeans for hay, 14 of oats, 14 of potatoes, 6 of tobacco, and 4 of cowpea hay. Most of the remaining plats are occupied, either singly or in mixtures, by red clover, alsike clover, sweet clover, timothy, red-top, and alfalfa. Some of the alfalfa plats have been a partial failure, and yields from such plats were not used in the study reported here. Mention should also be made of the fact that one cropping plan consists of tobacco followed by three years of fallow.

All the cropping plans, except tobacco followed by fallow, are carried on in duplicate. Each crop of a particular cropping plan is grown on duplicate plats each year. For example, in a three-year rotation of corn, wheat, and clover, there are two plats of corn, two of wheat, and two of clover each year.

In locating plats for the rotation experiments the relative yields obtained in the uniformity tests were used in a very general way. The correlation between yields of replicated plats as finally determined was very small compared with a marked correlation between the yields of adjacent plats. This indicated that on the average a single replication had removed to a considerable degree the effect of soil heterogeneity. The average involved all the plats and therefore it does not necessarily follow that the vitiating effect of soil heterogeneity was removed by a single replication if one wished to compare, for example, two particular rotations.

If one is justified in locating plats on the basis of relative yields from a uniformity test, it should be possible to demonstrate a correlation between relative yields obtained in the uniformity tests and relative yields obtained after the particular experiment is begun.

METHODS

For this study relative yields obtained both in the uniformity test and after the rotation experiments were begun were expressed in percentages. The difference between yields of duplicate plats obtained the same year was expressed as a percentage of the mean yield of the duplicates. If the plat with the greater number gave the higher yield, a plus sign was prefixed to the percentage; if the plat with the smaller number gave the higher yield, a minus sign was prefixed to the percentage. For example, plats 7 and 117 are duplicates. In 1924, plat 7 yielded 15.5 bushels; its duplicate, plat 117, yielded 17.8 bushels of wheat per acre. The difference is 13.9% of their mean yield, and since the plat with the higher number yielded the more, this percentage is recorded as a plus deviation. Similarly, the relative yields for these duplicate plats are determined for each of the other years involved in this study. By thus expressing the difference in yields between duplicates as a percentage of their mean yield, a study of the correlation of the relative yields of duplicate plats was very much facilitated.

THE UNIFORMITY TESTS

In Table 1 are shown the correlations between the difference in yields of duplicate plats revealed by the uniformity test with oats in 1923 and the difference in yield obtained from the same duplicates from 1924 to 1929, inclusive. In 1924, a uniformity crop of wheat was grown and in later years the several crops included in the rotation experiment were grown.

TABLE 1.—*Correlation between relative yields from duplicate plats of oats in 1923 and relative yields and relative average yields from the same duplicate plats of other crops in 1924 to 1929, inclusive.*

Correlation between relative yields in 1923 and	n	r
1924	130	+0.38±0.05
1925	130	+0.35±0.05
1926	126	+0.48±0.05
1927	128	+0.41±0.05
1928	120	+0.42±0.05
1929	136	+0.27±0.05
Average of 1925 to 1929, inclusive	115	+0.60±0.04

The correlations are all positive and statistically significant according to the probable errors or to the test suggested by Fisher.[6] This shows that the differences in yielding capacity between duplicate plats as revealed by the uniformity crop of oats tended to persist throughout the subsequent years even though several kinds of crops were grown under different treatments. The greatest correlation coefficient was found between differences in average yields obtained in 1925 to 1929, inclusive, and differences in yields obtained with the uniformity crop of oats.

In Table 2 similar data are shown on the relation between relative yields obtained from duplicate plats of wheat in 1924 and relative yields of the crops that followed. Wheat, like the oats, was a uniformity crop and immediately preceded the rotation experiment.

TABLE 2.—*Correlation between relative yields from duplicate plats of wheat in 1924 and relative yields and relative average yield from the same duplicate plats of other crops in 1925 to 1929, inclusive.*

Correlation between relative yields in 1924 and	n	r
1925	130	+0.35±0.05
1926	126	+0.25±0.06
1927	128	+0.15±0.06
1928	120	+0.31±0.06
1929	128	+0.20±0.06
Average of 1925 to 1929, inclusive	115	+0.40±0.05

Here, as in the relation between oat yields and yields of the other crops, all the correlations are positive, although one of them is not statistically significant. The correlation between the relative difference in yields of duplicate plats of wheat in 1924 and the relative difference in yields of the same duplicate plats of crops in the rotation experiment in 1927 is +0.15 ± 0.06. A small correlation was also found between the differences in wheat yields and difference in crop yields obtained in 1929, but in this case the correlation (+ 0.20 ± 0.06) has some statistical significance. According to the test for significance suggested by Fisher, the P value of this correlation is approximately 0.03. The other correlations in this table are significant.

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[6] FISHER, R. A. Statistical methods for research workers. London: Oliver & Boyd. Ed. 2. 269pp. 1928.

For some reason the oats grown in 1923 seem to have been a more desirable uniformity crop for determining difference in the potential productivity of duplicate plats than was the wheat crop grown in 1924. In general the correlations in Table 1 are greater than those in Table 2.

TABLE 3.—*Correlation between relative average yields of duplicate plats of oats and wheat grown in 1923 and 1924, respectively, and relative yields and relative average yields from the same duplicate plats of other crops in 1925 to 1920, inclusive.*

Correlation between relative average yields in 1923 and 1924 and	n	r
1925	130	0.40±0.05
1926	126	0.44±0.05
1927	128	0.30±0.05
1928	120	0.40±0.05
1929	128	0.24±0.06
Average of 1925 to 1929, inclusive	115	0.55±0.04

The correlations between the relative difference in the average yields of duplicate plats of the uniformity crops and the yields obtained from the same duplicate plats during the five years the rotation experiment has been in progress are all positive and significant (Table 3). This is perhaps what one would expect in view of the relations pointed out in Tables 1 and 2.

The relative difference between duplicate plats in average yields from 1925 to 1929, inclusive, followed rather closely the relative difference in productivity revealed by the uniformity crops. A positive correlation of + 0.55 ± 0.04 was obtained. With such a high co-variation as indicated between these two sets of variables, one would be justified in making a correction in the average yields obtained during the five years the rotation experiment has been in progress on the basis of the average difference in productivity as revealed by the oats and wheat crops.

Since the correlation coefficient showing the relation between the yields of the uniformity crop of oats and the subsequent average yields of the crops in the rotation was the greatest, it should be used as the basis for any adjustment in yields. The correlation surface and the regression line showing this relationship are shown in Table 4 and in Fig. 1, respectively.

TABLE 4.—*Correlation surface showing the relation between the relative difference in the yields of duplicate plats of a uniformity crop of oats and the difference in average yields of the same plats later when cropped according to the plan of a rotation experiment.*

Difference in % in yields of oats 1923	Difference in % in average yields 1925–1929: —45	—35	—25	—15	—5	+5	+15	+25	+35	+45	
+55									1		1
+45					1				1		2
+35					1	1	1		1		4
+25					1	1	1			2	5
+15				3	1	3	1	2			10
+ 5			3	2	8	4	3				20
— 5			2	9	10	4	2	1	1		29
—15		1	4	1	6	3	2				17
—25		1	6	6							13
—35			1	2	2	1					6
—45	1	1	1	3	1						7
—55											
— 65											
—75											
—85	1										1
	2	3	17	26	31	17	10	3	4	2	

r = +0.60±0.04

THE ROTATION EXPERIMENT

With the relative differences in yield obtained from duplicate plats expressed in terms of percentages, it was possible to study the inter-annual correlation between consecutive crops of the rotation experiment. The correlation coefficients calculated are shown in Table 5.

TABLE 5.—*Correlations between relative differences in yields of duplicate plats of crops in the rotation experiment during successive years from 1925 to 1929, inclusive.*

Correlation between relative yields in	n	r
1925 and in 1926	126	+0.18±0.06
1926 and in 1927	124	0.43±0.05
1927 and in 1928	119	0.28±0.06
1928 and in 1929	118	0.36±0.05

Here again positive correlations were obtained, although one of them is of doubtful significance. The correlation between the relative yields of duplicate plats in 1925 and in 1926 is 0.18 ± 0.06 (P value approximately 0.05). On the whole, the correlations are not marked, yet they are of sufficient magnitude to indicate an appreciable positive association between the yields on successive years during the period the rotation experiment has been in progress.

DISCUSSION

The data presented here indicate that differences in natural productivity of soil may persist over a period of years even though the soil be subjected to various treatments. Moreover, the relation which was found between the yields of the uniformity crop of oats and the average yields of the subsequent crops in the rotation experiment discussed in this paper would seem to justify one in locating replicated plats on the basis of such a uniformity test and in such a manner as to equalize the difference in initial productivity as revealed by the uniformity test. In a paper to be published in the near future a description will be given of a uniformity test as the basis of locating triplicate plats for several field experiments with fertilizers.

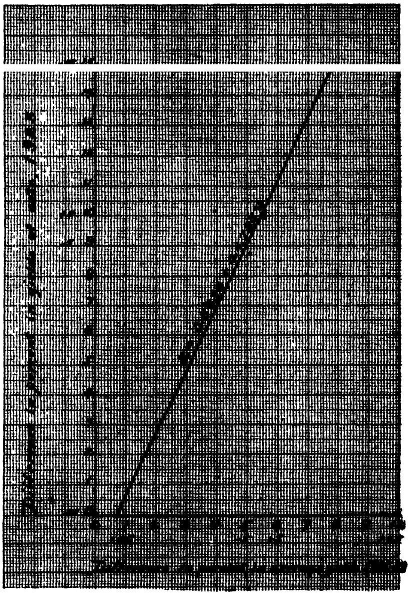

FIG. 1. The regression of relative differences among duplicate plats of crops grown during 1925 to 1929, inclusive, on relative differences among the same duplicate plats in yields of oats grown during 1923.

When uniformity crops have been harvested from an area before differential plat treatments have been applied, the yields from such uniformity crops may be of considerable value in interpreting the results obtained later after the experiment has been started. In the particular investigation reported here a correlation coefficient of + 0.60 ± 0.04 was obtained between the relative differences in yield of the uniformity crop of oats and the relative differences in the average yields of the crops grown later in the rotation experiment. The regression of relative differences in average yields in the rotation experiment on relative differences in yields of the oat crop is expressed by the equation $x = 0.6934 + 0.4783Y$.

An illustration may help to show how such a regression equation may be used. Suppose that the difference in yield between two particular plats as revealed by the uniformity test is + 15% and the difference in average yield as revealed by the five subsequent crops in the rotation experiment of the same plats is +30%. How much of the latter difference may be ascribed to the natural difference in productivity? Using the regression equation, the estimated difference in average yields of the five crops in the rotation experiment is found to be about + 5%. It follows that only 25 of the 30% may be ascribed to differential treatment, subject, of course, to a probable error.

To take another example, suppose that the difference between certain duplicate plats as shown by the uniformity test is —5% and the difference as shown by the average yields obtained in the rotation experiment is + 10%. Again using the regression equation, the estimated difference in average yields of the crops in the rotation experiment is found to be —5%. Hence, the actual difference obtained in the rotation experiment probably was somewhat less than would have been obtained if the duplicate plats had been equal in natural productivity at the time the experiment was begun.

Several regression relationships and various uses for them might be demonstrated, but the most important fact revealed by this investigation is that natural differences in productivity of plats persisted over a period of five years, even though these plats were subjected to different treatments.

TIME OF SEEDING SMALL GRAINS AFTER TOBACCO AND SAVING OF NITRATE[1]

P. E. KARRAKER[2]

A relatively large accumulation of nitrate is common in tobacco land in Kentucky in the fall after the crop has been removed.[3] This is due to the selection of productive land for the crop, the excellent tillage and frequently liberal fertilization given, and the nitrate coming from the roots, sucker growth, and other remains of the crop. In the absence of a proper cover crop, a large loss of nitrate from such land in the drainage water during the winter is probable.

In previous nitrate work by the writer, it was observed that apparently wheat seeded at or after the usual time (around October 15, the Hessian fly-free date at Lexington) frequently does not make sufficient growth to be very effective in taking up the nitrate in tobacco land even with average growth such as would enable the wheat to "winter" well. The use of rye and particularly of barley instead of wheat after tobacco is increasing in the bluegrass region of Kentucky. These crops are usually seeded earlier than wheat—particularly barley, which requires early seeding; preferably in the last half of September, to insure its successful over-wintering. Barley is a crop particularly well suited to follow tobacco, excepting late-cut tobacco, since it responds so well to the liberal supply of available nutrients in such land.

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[1] Contribution from the Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Published by permission of the Director. Received for publication May 9, 1930.

[2] Assistant Agronomist.

[3] KARRAKER, P. E. Nitrates and wheat yields after certain crops. Soil Science, 24:247–258. 1927.

It would be of some interest to have information on the gain in saving of nitrate in tobacco land through early seeding, for instance, of barley as compared with later seeding of wheat. The following experiment was carried out in 1928 and 1929 mainly on this point. Plats 17½ x 24 feet on the Experiment Station farm at Lexington were cropped to tobacco during the summer of 1928. Similar plats were cropped to corn. After removal of the crops (the tobacco on September 8 and the corn a few days before October 10), the plats were prepared and seeded to barley or wheat at various dates, or were left fallow. Two of the plats also received applications of sodium nitrate. Further details in handling the plats are shown in Fig. 1. Barley was seeded at the rate of 2 bushels per acre, and wheat at the rate of 1½ bushels per acre. Seeding was done with a one-row hand drill, in drills 8 inches apart and 1½ inches deep.

Nitrate nitrogen was determined in the plats at various times during the fall and at one time in the following spring. Samples of the growth were removed from plats 2, 3, 4, and 5 on December 29, 1928, from 12 different places, each 1 foot of drill row in length. This was done with a spading fork, getting as much of the roots as possible. The soil was washed from the roots in the laboratory. The sample from plat 2 was separated at the ground line into tops and roots. The oven-dry weights of these samples and the percentage nitrogen contained were determined and the amounts calculated to the acre basis.

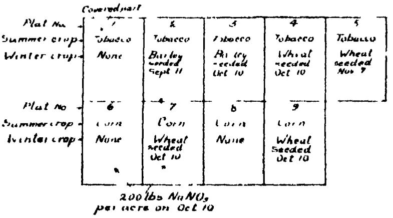

FIG. 1.—Arrangement and handling of the plats.

A part of plat 1, 10 x 10 feet in area, was protected from heavy rains during the fall and winter by a tarpaulin supported on a frame about 1 foot above the ground. The area was covered only during heavy rains until the middle of December, but continuously from then on until the nitrate determination in the following spring.

The dates of sampling for nitrate and the amounts found expressed as nitrate nitrogen are shown in Table 1. The amount of dry weight of the growth, the nitrogen contained in it, and the nitrogen in the growth plus the nitrogen in the soil for certain of the plats in December, 1928, are shown in Table 2. Examination of the data in Table 1, plats 1 and 8, shows fair accumulation of nitrate in the plats growing tobacco during the summer and small accumulation in the plats growing corn. The monthly rainfall, in inches, from September, 1928, to March, 1929, inclusive, recorded at the Lexington Weather Bureau Station 1 mile distant was as follows: September, 0.71; October, 2.68; November, 3.79; December, 1.92; January, 2.83; February, 3.37; and March, 3.67. This is lower than the normal rainfall for this period, particularly during September. Part of the smaller accumulation of nitrate after corn than after tobacco may be attributable to the poorer moisture condition in the corn plat due to later removal of this crop. On October 11, the percentage of water in plat 1, on which tobacco grew during the summer, was 17.10 and in plat 8, on which corn grew, 14.16. Probably the rainfall up to December 12 was not such as to carry nitrates down to an appreciable extent. Five and two-tenths inches fell between October 19 and December 4. The nitrate determinations for these dates (plat 1) indicate only small downward movement. It was not until the latter part of February and the first of March that rainfall occurred which brought about much downward movement. The data show that nitrate was largely removed from the surface foot during the winter; however, part of this amount was held in under layers. The normal rainfall at Lexington during the September-March period is about 23 inches. The total rainfall during this period at the time of this experiment was about 19 inches. Probably normal rainfall would have carried practically all nitrate below the sampled depth and beyond subsequent use by the crop.

The data, particularly with reference to the December 12 determinations, show the expected greater effect of early seeding of small grain crops than of the later seedings in diminishing the content of nitrate in the soil. The nitrate content is much smaller in the soil of the plat seeded to barley on September 11 than in the soil of the plat seeded to barley on October 10. It is interesting to note that the soil of the plat seeded to barley on October 10 contained less nitrate than the soil of the plat seeded to wheat at the same time, indicating a closer use of nitrate by barley than by wheat. As shown in Table 2, at the time of sampling, the barley growth contained a larger amount of nitrogen than the wheat growth, in the case of these two plats.

It will be noted further that the amount of nitrate in the wheat plat seeded October 10 is practically the same as in the wheat plat seeded November 7 and probably about the same as in unplanted plat 1. However, the total nitrogen in the wheat growth on the plat seeded October 10 was larger than that in the wheat growth on the plat seeded November 7, as shown in Table 2. The wheat on the plat seeded October 10 wintered satisfactorily and made excellent growth the following spring. The wheat on the plat seeded November 7 also wintered fairly well. In general, the results emphasize the effectiveness of the relatively large growth of the early-seeded barley in removing nitrate from the soil and preventing loss in the drainage water, and the comparative ineffectiveness in this respect of an average growth of wheat seeded at or after the usual time.

Table 1.—*Nitrate nitrogen in soils in pounds per acre.**

	Depth			1928			1929
Plat No.	in inches	Sept. 10	Oct. 11	Oct. 19	Dec. 4	Dec. 12	Mch. 25
1, covered part	0-12	3.3	—	20.0	24.4	—	25.5
	12-24	—	—	—	—	—	25.4
	24-30	—	—	—	—	—	6.7
1, uncovered part	0-12	1.6	12.6	17.0	15.5	—	5.1
	12-24	1.9	9.5	5.8	14.5	—	10.5
	24-30	0.9	—	1.2	4.0	—	7.7
2	0-12	1.9	—	11.0	1.4	1.9	1.0
	12-24	—	—	—	1.8	0.9	
3	0-12	1.4	13.6	18.0	—	12.9	
	12-24	—	—	—	—	6.1	
4	0-12	1.4	—	—	—	17.6	2.1
	12.24	—	—	—	—	14.7	
5	0-12	1.4	—	—	—	14.9	3.6
	12-24	—	—	—	—	20.5	
6	0-12	—	—	23.0	19.2	—	3.6
	12-24	—	—	—	17.9	—	13.7
	24-30	—	—	—	—	—	9.6
8	0-12	—	2.2	4.6	4.7	—	4.3
	12-24	—	—	—	7.2	—	5.3
	24-30	—	—	—	—	—	1.4

*In calculating the amounts to the acre basis the following acre weights of soil were used: 0-12 inch depth, 2,040,000 pounds; 12-24 inch depth, 3,490,000 pounds; 24-30 inch depth, 1,830,000 pounds. These values were obtained by roughly determining the volume weights of the soils of the three depths.

Nitrate determinations for the covered part of plat 1, where leaching was prevented, showed practically the same amount of nitrate present in the late fall and in the early spring. This work was done for any information it would give on a possible reduction of nitrate

TABLE 2.—*Dry weight and nitrogen content of the plant growth and nitrate nitrogen in the soil in pounds per acre, December, 1928.*

Plat No. and crop	Plant growth* Dry weight	Plant growth* Nitrogen	Nitrate nitrogen in top 2 feet of soil†	Nitrogen in growth plus nitrate nitrogen in top 2 feet of soil
2, barley, seeded Sept. 11:				
Tops	1,064	33.5	—	—
Roots	678	12.6	—	—
Total	1,742	46.1	2.8	48.9
3, barley, seeded Oct. 10	478	19.8	19.0	38.8
4, wheat, seeded Oct. 10	295	9.8	32.3	42.1
5, wheat, seeded Nov. 7	53	1.8	35.4	37 2

*Samples collected December 29, 1928.
†December 12, 1928.

during the winter by microbial activity or in some other way than removal by plant growth or drainage water. Assuming negligible production of nitrate during the winter, the work suggests that there is no reduction of nitrate during this period apart from plant use or drainage removal.

Plats 6 and 8, cropped to corn during the summer, were left fallow. Plat 6 received an application of sodium nitrate on October 10, containing about 30 pounds of nitrogen per acre. On December 4, according to the determinations, plat 6 contained 25.2 pounds more nitrate nitrogen in the surface 2 feet of soil than plat 8 (Table 1). Nitrate determinations in the third foot probably would have found most of the balance of the nitrogen from the fertilizer application. On March 25 following, plat 6 contained 15.9 pounds more nitrate nitrogen in the surface 2½ feet of soil than plat 8. There has been considerable shift, also, in concentration of nitrate from the surface to lower depths. Wheat seeded on plats 7 and 9, growing corn during the summer, made much less growth during the fall than wheat seeded at the same time on the plat which grew tobacco during the summer. Differences in moisture conditions referred to above may account for some part of this. No effect could be observed from the sodium nitrate application on plat 7 in increasing growth of wheat in the fall as compared with plat 9. Growth, however, was observed to be considerably better on plat 7 than on plat 9 during the following spring. Heavier rainfall during the winter and larger removal of nitrate in the drainage water probably would have largely prevented this effect in the spring.

Due to the dry and, in particular, the cool fall, the growth made and nitrogen contained in this growth were not large even in the case of the early-seeded barley plat. On November 30, 1927, samples of a luxuriant barley growth, tops and roots, were removed from a highly productive field on the Experiment Station farm. The field had been in tobacco during the summer. The total dry weight of barley growth was found to be 4,738 pounds per acre and the total nitrogen contained in this growth, 156 pounds. The large amount of nitrogen indicates the large loss of this nutrient possible from such a soil without a satisfactory cover crop.

SUMMARY

Comparisons were made between the effectiveness of small grain crops seeded at different times in the fall in taking up nitrate from the soil and reducing loss in the drainage water. In particular, comparison was made between barley seeded early and wheat seeded at or after the usual time on land growing tobacco during the summer where considerable production of nitrate during the fall is to be expected. Small plats were cropped to tobacco during the summer of 1928. After removal of this crop the plats were seeded to barley or to wheat at different times or were left fallow. Nitrates were determined in the soil at several different times. The nitrogen in the growth was determined in early winter. The large growth of early-seeded barley was effective in reducing the content of nitrate in the soil to a low level. Wheat seeded at or after the usual time was comparatively ineffective in this respect. Work was done and information presented on certain other related points.

AGRONOMIC AFFAIRS

ANNUAL MEETING OF SOCIETY

The twenty-third annual meeting of the Society will be held at the Raleigh Hotel in Washington, D. C., Thursday and Friday, November 20 and 21.

NEWS ITEMS

D. I. AQUINO, who has been studying at the Iowa State College for the past four years, received his doctor's degree in June and has returned to the Philippine Islands where he will resume his duties as Assistant Professor of Soil Technology at the University of the Philippines at Los Banos.

G. G. POHLMAN, who received his Doctor's degree in Soil Bacteriology from Iowa State College in June, was appointed Assistant Professor of Agronomy at the West Virginia University, effective July 1.

R. A. **PENDLETON** has recently been appointed Assistant Soil Technologist in Sugar Beet Investigations with the Bureau of Chemistry and Soils and is stationed at Grand Rapids, N. D. For the past two years Mr. Pendleton has held a fellowship sponsored by the Chilean Nitrate of Soda Company, at Iowa State College, where he received his Doctor's degree in Soil Fertility in June.

John L. **SULLIVAN**, who has been doing graduate work in Soil Bacteriology at Iowa State College for the past two years, has recently accepted a position at the Morehead State Normal School, Morehead, Kentucky.

DR. F. J. STEVENSON, formerly Assistant Geneticist, University of Minnesota, has accepted the position of Geneticist in the Office of Horticultural Crops and Diseases, U. S. Dept of Agriculture. Dr. Stevenson will do work in potato breeding with headquarters at Washington, D. C.

CORRECTIONS

Attention has been called to an error in the legends appearing in Figs. 1 and 2 on page 722 of this volume in the article on "The Chemical Composition of Consecutive Cuttings of *Andropogon virginicus* and *Danthonia spicata*," by R. B. Dustman and A. H Van Landingham. The expressions "primary cuttings" and "consecutive cuttings" should be interchanged in each of the two graphs.

Also, in the article by E. P. Deatrick on pages 736 and 737 of the current volume, the expression "$1/\Delta$" in the numerators of the formulae for S, T, U, and V should be deleted.

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THE LODGING OF SOYBEANS[1]

F. A. WELTON AND V. H. MORRIS[2]

For many years the practice has been growing among farmers to mix soybeans with corn in the silo in order to have a better balanced and more nutritious feed than results from the ensiling of corn alone. Formerly, it was the general custom to grow each crop in a separate field and to mix the two together as they went into the silo. In more recent years it has become common to sow the two crops together in the same field, planting the seeds of soybeans sometimes in the same hills with the corn, sometimes midway between the corn hills, or perhaps in alternate rows with the corn. Various methods of distributing the seed have been followed, depending on whether the corn was planted in hills or drilled.

In growing the two crops together, much difficulty is often experienced at harvest time in securing and saving the soybean plants. When grown in the shade of the corn, soybean plants appear to be less sturdy than when grown in the open, and, as a result, they are inclined to fall down on the ground, thus rendering difficult the operation of picking them up successfully with a corn binder at harvest time. Consequently, many of them are simply run over and lost. Of course it is recognized that the character of growth made by soybeans varies somewhat with the variety; some sorts being characterized by the development of long, slender, vine-like stems, which, when growing in close proximity to plants like corn, are inclined to twine around the stalks of the latter. The majority of the varieties best adapted to the northern states, however, are erect and sturdy when grown in the open. These normally erect-growing varieties, however, show a tendency to fall over or lodge when grown in corn.

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OBJECT

The purpose of the work presented in this paper was to ascertain the cause of the development of weak stems in and the consequent lodging of soybeans. A study was made of the effect on the plants of variation in light, because it is in respect to this factor chiefly that the environment of soybeans grown in corn is modified. In habit of growth corn so overtops soybeans that in growing the two crops together the soybeans are developed under the influence of more or less reduced light, the degree of the reduction depending on the thickness of stand of corn, the earliness of the variety, the manner of planting, and many other things.

MATERIAL AND METHODS

In order to study the effect of reduced light on the composition of the stems, plants were shaded artificially. A wooden frame approximately 6 feet square and about 5 feet high was covered with a single layer of cheesecloth, ample provision being made for free circulation of air at both top and bottom of the frame. The plants covered were grown in a general field where the beans were drilled in rows 28 inches apart and cultivated. The frame was not placed in position until July 30, the plants then being in the late blooming stage and rather well developed.

At the time of harvest, but before the leaves began to fall, a sample of the shaded and unshaded plants adjoining was taken for analysis. The leaves were removed and the lower two-thirds only of the stems were used. These were cut into pieces one-half to three-fourths inch long, placed in wide-mouthed, glass-stoppered bottles, covered with alcohol, the strength of which, after allowing for the moisture contained in the plants, was about 70%, and then heated for an hour or so at approximately 78° C. The samples were then set aside and allowed to stand two or three months before analysis.

Samples were gathered in three consecutive seasons, *viz.*, 1923, 1924, and 1925. In the same years samples of soybeans grown in and outside of corn were also gathered and preserved for analysis. In 1923, only one variety was used, but samples were taken on two different dates, August 9 and September 13. In 1924, three varieties were sampled, namely, Elton, Ebony, and Cloud. Samples of two varieties, Manchu and Peking, were taken in 1925. Generally speaking, the stems of the Elton and Manchu varieties are strong and erect, while those of the Ebony, Cloud, and Peking are smaller, more slender, and under certain conditions inclined to become viny.

Aside from total dry matter, analyses were made for certain of the constituents of which the dry matter is composed, compounds the formation of which would be most likely to reflect variations in intensity of light and those of which the frame work or skeleton of the plants is largely composed. These consisted of the free reducing sugars, inverted sugars, easily hydrolyzable carbohydrates, cellulose, and lignin.

RESULTS

The results of analyses of the plants shaded artificially with cheesecloth in 1923, 1924, and 1925, together with those of unshaded or check plants grown in the same seasons, were as shown in Table 1.

TABLE 1.—*Effect of shade on composition of soybean stems; shade provided by cheesecloth.*

Material	1923		1924		1925	
	Unshaded %	Shaded %	Unshaded %	Shaded %	Unshaded %	Shaded %
Moisture....... .	68.9	73.4	70.6	73.2	66.4	70.4
Dry matter.......	31.1	26.6	29.4	26.8	33.6	29.6
Free reducing sugars..	1.3	0.8	2.0	1.9	1.6	1.7
Inverted sugars. .	0.0	0.0	0.0	0.2	0.0	0.1
Easily hydrolyzable carbohydrates	5.9	4.1	5.5	5.0	4.9	4.4
Cellulose..	3.5	3.3	3.5	3.4	3.8	3.0
Lignin.	12.3	11.3	11.6	10.5	15.5	14.8
Total carbohydrates ...	23.0	19.5	22.6	21.0	25.8	24.0

In each of the three years less dry matter and less total carbohydrates were found in the shaded than in the unshaded plants. The smaller quantity of total carbohydrates was due chiefly to the presence of less easily hydrolyzable carbohydrates, less cellulose, and less lignin. Each year the plants grown under the cheesecloth developed weak stems and fell over or lodged as illustrated in Fig. 1.

Apparently, the same kind of modification in the stems of soybean plants is brought about through shade imposed by growing corn plants, for in 1923 similar differences were found in soybeans grown in and outside of corn. The results (Table 2) show that on both dates the soybeans grown in the corn as compared with those grown in the open contained less dry matter and less total carbohydrates.

TABLE 2.—*Effect of shade on composition of soybean stems; soybeans grown in corn, 1923.*

Material	August 9 Outside corn %	 Inside corn %	September 13 Outside corn %	 Inside corn %
Moisture	75.7	77.4	65.7	71.3
Dry matter	24.3	22.6	34.3	28.7
Free reducing sugars	0.5	0.6	1.7	1.3
Inverted sugars	0.4	0.3	0.4	0.3
Easily hydrolyzable carbohydrates	3.9	3.2	6.7	4.6
Cellulose	3.1	3.3	4.2	3.6
Lignin	9.9	8.5	13.7	12.2
Total carbohydrates	17.8	15.9	26.7	22.0

The smaller quantity of total carbohydrates was due to the development of smaller quantities of inverted sugar, easily hydrolyzable carbohydrates, and lignin. On the latter date there was also less cellulose in the soybeans grown in the corn.

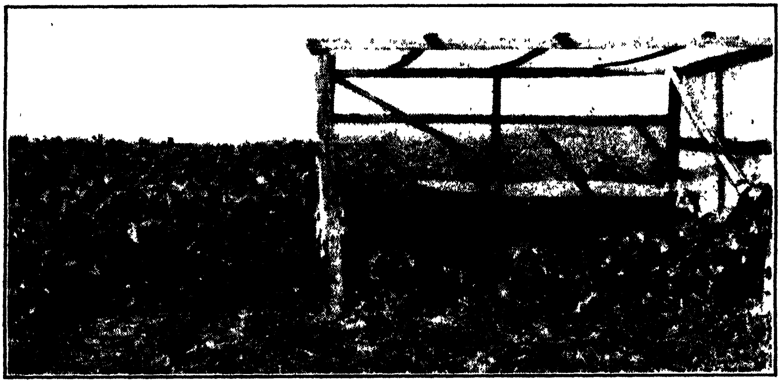

FIG. 1.—Lodging of soybeans induced by artificial shading with cheesecloth.

Further evidence to the effect that the dry matter and the total carbohydrate content of the stems of soybeans grown in corn are reduced by the shade of the latter was obtained in 1924 and again in 1925 (Tables 3 and 4).

TABLE 3.—*Effect of shade on composition of soybean stems; soybeans grown in corn, 1924.*

Material	Elton Outside corn %	 Inside corn %	Ebony Outside corn %	 Inside corn %	Cloud Outside corn %	 Inside corn %
Moisture	66.2	71.8	70.3	72.1	67.8	69.4
Dry matter	33.8	28.2	29.7	27.9	32.2	30.6
Free reducing sugars	1.5	2.2	1.6	1.3	1.8	1.3
Inverted sugars	2.9	0.3	0.2	0.1	0.6	0.3
Easily hydrolyzable carbohydrates	7.1	4.7	5.9	5.3	8.8	7.9
Cellulose	3.9	3.3	7.8	8.4	4.4	4.1
Lignin	14.1	12.8	10.2	9.0	12.8	13.5
Total carbohydrates	29.5	23.3	25.7	24.1	28.4	27.1

The results obtained in 1925 on samples of two more varieties, Manchu and Peking, were as shown in Table 4.

TABLE 4. *Effect of shade on composition of soybean stems: soybeans grown in corn.*

	Manchu		Peking	
Material	Outside corn %	Inside corn %	Outside corn %	Inside corn %
Moisture...	58.3	65.0	68.3	71.2
Dry matter...	41.7	35.0	31.7	28.8
Free reducing sugars	0.4	0.3	1.1	1.4
Inverted sugars	0.4	0.2	0.0	0.4
Easily hydrolyzable carbohydrates	6.2	5.5	6.4	6.6
Cellulose..	4.7	3.9	2.8	2.7
Lignin.	22.1	17.2	14.2	13.3
Total carbohydrates	33.8	27.1	24.5	24.4

From Tables 3 and 4 it may be seen that in the case of all five varieties the plants grown in the corn contained less dry matter and less total carbohydrates than did those grown in the open. The smaller quantities of total carbohydrates are, with few exceptions, due to the presence of less inverted sugars, less easily hydrolyzable carbohydrates, less cellulose, and less lignin.

These tables, based on the percentage composition, reflect only a part of the real difference, for as a result of growing in the shade the form of the plants was materially changed; the stems of the shaded ones being longer, slenderer, and consequently more pliable. The actual difference in strength of stem is, perhaps, best indicated by the composition of a given length rather than of a given weight of culm as shown in Tables 5 and 6 which give the quantity of the various constituents in mgr per linear cm of culm.

TABLE 5. *Effect of shade on composition in mgr per linear cm of culm of soybean stems, shade provided by corn plants, 1924*

	Elton		Ebony		Cloud	
Material	Outside corn	Inside corn	Outside corn	Inside corn	Outside corn	Inside corn
Moisture ..	158.8	89.3	199.2	93.9	210.6	114.9
Dry matter...	81.1	35.1	84.1	36.3	100.0	50.7
Free reducing sugars.	3.6	2.7	4.5	1.7	5.6	2.2
Inverted sugars	7.0	0.4	0.6	0.1	1.9	0.5
Easily hydrolyzable carbohydrates.	17.0	5.8	16.7	6.9	27.3	13.1
Cellulose..	9.4	4.1	22.1	10.9	13.7	6.8
Lignin.	33.8	15.9	28.0	11.7	39.8	22.3
Total carbohydrates ..	70.7	29.0	72.8	31.4	88.2	44.9
Total length (cm) of stems in 100 grams..	417	804	353	768	322	604

From the bottom row of figures in each of these tables, it can be seen that in order to make 100 grams there was required a much greater length of stems of the beans grown inside than of those grown

TABLE 6.—*Effect of shade on composition in mgr per linear cm of culm of soybean stems; shade provided by corn plants, 1925.*

	Manchu		Peking	
Material	Outside corn	Inside corn	Outside corn	Inside corn
Moisture	144.0	67.4	268.9	62.5
Dry matter	103.0	36.3	124.8	25.3
Free reducing sugars	1.0	0.3	4.3	1.2
Inverted sugars	1.0	0.2	0.0	0.4
Easily hydrolyzable carbohydrates	15.3	5.7	25.2	0.6
Cellulose	11.6	4.0	11.0	2.4
Lignin	54.6	17.8	56.0	11.7
Total carbohydrates	83.5	28.1	96.5	21.4
Total length (cm) of stems in 100 grams	405	964	254	1,139

outside of the corn. Moreover, it can be seen that the quantity of all the constituents contained in 1 cm of culm expressed in mgr was much greater in the plants grown outside than in those grown inside of the corn.

DISCUSSION

The finding of less dry matter in the shaded soybean plants is in agreement with the work of Garner and Allard.[3] Shading has been found to result in a reduction of dry matter also in oats and wheat.[4] Weakness of plant stems has been attributed to lack of sufficient light by many others. The carbohydrate compounds to which the reduction in dry matter was chiefly due consisted principally of easily hydrolyzable carbohydrates, cellulose, and lignin; all being products which contribute either directly or indirectly to toughness and rigidity of stems. The stems with low dry matter content were relatively soft, succulent, pliable, and inclined to lodge.

CONCLUSIONS

Soybean plants grown under the influence of reduced light contained less dry matter and less total carbohydrates than did those grown in the open.

The reduction in total carbohydrates and, therefore, indirectly in total dry matter, was due in general to the development of less easily hydrolyzable carbohydrates, less cellulose, and less lignin.

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[3] GARNER, W. W., and ALLARD, H. S. Effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res., 18:553–606. 1920.

[4] WELTON, F. A. Lodging in oats and wheat. Bot. Gaz., 85:121–151. 1928.

THE EFFECT ON PLANT GROWTH OF TREATING SOILS WITH COPPER-CARRYING PYRITE[1]

H. V. SMITH[2]

Sulfur has been used on land for many years, either as a soil amendment or as a fertilizer. Its use, however, is limited to two or three specific soil conditions. It may supply sulfur directly, during oxidation it may make other elements more available, or it may modify the soil either physically or biologically. It has been used profitably in the great basaltic soil areas in the Pacific Northwest where it has been shown that the application of sulfur increases crop yields materially (1, 2).[3] In other humid regions of the United States, particularly in New Jersey, Kentucky, and Maryland, it has also been used more or less extensively (3, 4, 5).

Soils and irrigation waters in Arizona contain greater or less amounts of white alkali salts, prominent among which is sodium sulfate. There is thus no deficiency of soluble sulfates in Arizona soils and as a result we would expect no beneficial returns on this score from the application of a sulfur-carrying soil amendment. Occasionally, however, spots of black alkali (mixtures of Na_2CO_3, NaOH, and $NaHCO_3$) are encountered in Arizona soils. Such soils have been shown by Kelly and Thomas (6), Joffe (3), and others to yield to sulfur treatment. Gypsum, the most common sulfur-carrying soil amendment, is valuable for its soluble calcium, while such compounds as alum, iron sulfate, flowers of sulfur, etc , are valuable for their resulting acidity which liberates soluble calcium in the soil. Although gypsum deposits are quite common in Arizona many of them are not readily accessible and those that are may be located far from farming districts. The freight rates and the high initial cost of Louisana sulfur make this imported product too expensive to use on agricultural lands in Arizona, thus it seemed desirable to investigate the suitability of the waste pyrite, produced in large quantities in the refining of sulfide ores in Arizona and in northern Mexico, for this purpose.

The object of this investigation was to determine the rates of oxidation of two varieties of pyrite in various soils and to ascertain whether or not the copper contents had a toxic effect on vegetation when applied in reasonable amounts.

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[1] Contribution from the Dept. of Agr. Chem. and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Received for publication May 19, 1930.

[2] Assistant Professor,

[3] Reference by number is to "Literature Cited," p. 915.

EXPERIMENTAL

Nine soils were secured from different parts of the United States. They varied widely in texture, hydrogen-ion concentration, soluble salt content, and water-soluble sulfur content. A description of the soils and the locations from which they were secured is as follows:

Soil	Soil type	Location
A	Unmapped clay loam	Tumanoc Hill, Tucson
B	Gila fine sandy loam	Old U. of A. Farm, Tucson
C	Gila loam	Yuma Valley Farm
D	Laveen clay loam	Experiment Farm, Mesa
E	Yakima sandy loam	Oregon
F	Sassafras loam	New Jersey
G	Waverly silt loam	Kentucky
H	Carrington loam	Iowa
I	Houston clay loam	Texas

The United States Bureau of Mines at the University of Arizona procured the pyrite samples; one from the United Verde Copper Company at Jerome, Arizona, which is black in color and so soft that it may easily be broken or ground into fine particles, and the second from the Moctezuma Copper Company, Nacozari, Sonora, Mexico, which is hard and has a yellowish metallic luster similiar to fool's gold.

Chemical analyses and screen tests of these two samples were made in the United States'Bureau of Mines laboratories and appear in Table 1.

SULFUR OXIDATION

The rate of oxidation of the pyrites and, for comparative study, of flowers of sulfur, were determined in the different soil types by thoroughly mixing 2 grams of sulfur or its pyrite equivalent with 200 grams of soil, placing in tumblers, bringing them to optimum moisture content, incubating them at 37° C for six weeks, and determining the sulfate content of each at the end of the period.

The Nacozari pyrite is somewhat resistant to oxidation and breaks down less readily than does the Jerome pyrite or the flowers of sulfur. The amounts of sulfur oxidized in the various soils during the six weeks period ranged from 0.48 to over 10%, the Nacozari pyrite from a trace to 2%, and the Jerome pyrite from 1.3 to 6.1%. The detailed results need not be given. It will be seen that the Nacozari pyrite was not oxidized as readily as Jerome pyrite, largely because of the differences in the size of particles in the two.

TABLE 1.—*Composition of pyrite.*

Composition	By-product pyrite, Moctezuma Copper Co., Nacozari, Sonora, Mexico %	Pyrite from United Verde Copper Co., Jerome, Arizona, mixed with C. P copper carbonate* %
Total copper	1.63	1.26
Acid-soluble copper	0.04	0.35
Iron	38.9	43.3
Sulfur	42.18	40.50
CaO	0.12	0.10
Insoluble	14.80	3.60

Screen Tests

Nacozari pyrite Mesh	 %	Jerome pyrite Mesh	 %
20	0.107	20	1.240
35	1.890	35	13.857
48	4.7[illegible]	48	12.300
65	14.570	65	9.493
80	4.276	79	1.496
100	24.494	100	6.843
150	24.139	150	6.782
200	15.420	200	7.427
200	10.386	200	40.562

*This product originally contained 0.92% of copper but was mixed with C. P. copper carbonate to raise the copper content to an amount which would be comparable with the pyrite from Nacozari, Sonora, Mexico

POT CULTURE WORK WITH PYRITE

After finding that the sulfur in the pyrite was capable of oxidation and that the copper present apparently had little detrimental effect on sulfofication, pot-culture experiments were started. Nine series of 10-quart flower pots which were provided with drainage holes were filled with 9.5 kilograms of the various soils and pyrite added to all but the controls. The Arizona soils were treated in quadruplicate, while the others were used in duplicate. Each series was divided as follows for the 1925 26 crop:

1, third of pots, control, no treatment.
2, third of pots, Nacozari pyrite equivalent to the S in 5 tons of gypsum.
3, third of pots, Jerome pyrite equivalent to the S in 5 tons of gypsum.

After mixing the soil and pyrite together, they were placed in the pots and brought to optimum moisture content. Barley seedlings (7 in number) were then transplanted to each pot and watered as occasion demanded with distilled water until they were mature. The pots were placed in a screen garden which is fully protected from insects and birds.

No consistent ill or beneficial effects of the treatments were noted during the first year, therefore it was planned to continue the experiment for three years and to supplement the treatment as follows for the 1926–27 crop: The Arizona soils, which were in quadruplicate the first year, were divided into duplicate series so that light and heavy applications of pyrite might be tried. The black-alkali soil from the University Farm was given no more pyrite, but half the pots were treated with flowers of sulfur. In addition to the amounts used the previous year, the other soils received heavy applications of pyrite as indicated in the following chart:

A. Tumonoc Hill	pots 1– 4, check, no treatment
	pots 5– 6, sulfur equivalent to that in 5 tons gypsum
	pots 7– 8, sulfur equivalent to that in 10 tons gypsum
	pots 9–10, sulfur equivalent to that in 5 tons gypsum
	pots 11–12, sulfur equivalent to that in 10 tons gypsum
B. University Farm, Tucson	pots 1– 2, 6 grams flowers of sulfur
	pots 3– 4, check, no treatment
	pots 5– 6, 6 grams flowers of sulfur
	pots 7– 8, no addition
	pots 9–10, 6 grams flowers of sulfur
	pots 11–12, no addition
C. Yuma	same treatment as Tumonoc Hill soil
D. Mesa	same treatment as Tumonoc Hill soil
E. Oregon	pots 1– 2, check, no treatment
	pots 5– 6, sulfur equivalent to that in 10 tons gypsum
	pots 9–10, sulfur equivalent to that in 10 tons gypsum
F. New Jersey G. Kentucky H. Iowa I. Texas	Same treatment as Oregon soil

The same soils without additional sulfur treatments were used for the 1927–28 crop.

EFFECT OF TREATMENTS UPON CROP YIELDS AND UPON CHEMICAL COMPOSITION OF SOILS

Table 2 shows certain chemical changes which have taken place in the soils during the three years of the experiment.

The equations usually given for the oxidation of the pyrite are:

$$4FeS_2 + 15\ O_2 + H_2O \longrightarrow 2Fe(SO_4)_3 + 2H_2SO_4$$
$$Fe_2(SO_4)_3 + H_2O \longrightarrow Fe_2O(SO_4)_2 + H_2SO_4$$
$$Fe_2O(SO_4)_2 + H_2O \longrightarrow Fe_2O_2SO_4 + H_2SO_4$$

The calcium in the gypsum which is later formed, providing calcium carbonate or a lime phosphate is present, replaces the sodium in the soil zeolites, thus destroying any black alkali present, and tends to promote a desirable physical condition in the soil. In either case, an abundance of available sulfate is formed in the soil.

The soils which were used in this experiment may be divided into two classes depending upon their original lime content and hydrogen-ion concentration The soils from Arizona and Texas all had an abundance of lime and all had a reaction above pH 7.0, while the soils from Oregon, New Jersey, Kentucky, and Iowa were either neutral or slightly acid and did not contain a reserve supply of lime, thus instead of forming gypsum from the H_2SO_4, as was the case in the high lime soils, the acid produced from the sulfur oxidation tended to lower the pH (Table 2).

The effect of the treatments upon crop yield may be seen by an inspection of Table 3. The weight of the crop produced on the check pot has been given a value of 100, and the others have been calculated to this basis.

The soil from Tumonoc Hill, Tucson, appeared to be rendered more productive by treatments the first year, but during the second and third years the initial crop increases were reduced. The reaction of the soil changed during the three years from 8.17 to 8.08. Copper determinations on the aerial portions of the plants show the largest amounts of copper in the pots having the poorest growth. The soluble-salt content of the soils is doubled in the pots receiving heavy treatments of pyrite, and sulfates were increased 10 times.

The black-alkali soil from the old University of Arizona Farm, Tucson, responded readily to sulfur treatment and less readily to pyrite treatment, as shown by the crop weights. The amounts of copper taken up by the plants which received the heavy applications of pyrite are relatively high. During the third year a partial crop grew on the pyrite-treated soils because some of the alkali had been neutralized by the pyrite and had subsequently been leached from the soils. The growth of crops, the neutralization of some of the black alkali from the soil, and the pyrite treatment were all effective in lowering the pH of the soil during the three years.

TABLE 2.—*Chemical analyses of the soils before treatment and after growing barley crops for three successive years.*

Treatment	First year				Treatment	Second year				Treatment	Third year				Cu in aerial portion of plants†
	TSS*	Ca†	SO_4†	pH		TSS*	Ca†	SO_4†	pH		TSS*	Ca†	SO_4†	pH	
						A, Desert Laboratory									
					1–4	1,042	75	500	8.23	1–4	437	45	T	8.11	4.93
Original	1,139	120	75	8.23	5–6	935	45	450	8.08	5–6	717	45	185	8.10	14.08
1–4	913	90	125	8.17	7–8	1,047	75	750	8.14	7–8	392	45	T	8.30	10.41
5–8	708	45	130	8.59	9–10	1,179	120	900	7.99	9–10	2,047	75	1,125	8.13	12.13
9–12	880	90	210	8.49	11–12	1,567	225	1,500	7.90	11–12	1,998	90	1,100	8.08	25.81
						B, University of Arizona									
Original	4,161	30	1,000	10.20	1–2	2,397	0	1,500	9.01	1–2	1,489	0	425	9.20	11.86
					3–4	1,826	0	T	9.64	3–4	1,544	0	T	9.45	
1–4	1,573	15	275	10.23	5–6	2,247	0	1,500	9.04	5–6	1,674	0	500	9.14	7.6
					7–8	1,517	0	T	9 65	7–8	1,894	0	375	9.45	
5–8	1,724	15	275	10.25	9–10	2,445	0	2,250	8.95	9–10	1,376	0	500	9.06	37 26
					11–12	2.245	0	1,200	9.45	11–12	1,897	0	425	9.45	42.27
9·12	1,663	15	750	10.18											
						C, Yuma									
										1–4	3,771	120	2,250	8.19	23.02
Original	4,470	388	1,890	8.43	1–4	1,838	135	2,500	8.45	5–6	3,889	180	2,375	8.03	34.28
1–4	1,840	180	990	8.73	5–6	1,700	135	1,750	8.07	7–8	2,601	180	1,500	8.13	34.09
5–8	1,946	210	1,170	8.73	7–8	3,262	405	2,500	8.71	9–10	4,983	300	3,000	8.05	29.28
					9–10	2,165	225	2,500	7.98						
9–12	1,856	225	1,125	8.44	11–12	3,286	450	4,200	8.15	11–12	3,653	345	2,250	7.95	38.03
						D, Mesa									
					1–4	941	0	0	9.00	1–4	546	0	0	8.36	15.80
Original	1,287	30	70	8.84	5–6	828	0	0	8.72	5–6	613	0	0	8.27	27.28
1–4	875	0	0	8.96	7–8	628	0	T	8.73	7–8	512	0	0	8.19	48.72
5–8	901	0	0	8.93	9–10	856	0	T	8.72	9–10	439	0	0	8.13	28.99
9–12	827	15	90	8.95	11–12	809	0	580	8.50	11–12	425	15	T	8.03	37.69

							E, Oregon								
Original	455	30	T	7.70	1-2	449	0	T	7.75	1-2	378	0	0	7.74	16.60
1-2	543	15	0	8.02	5-6	446	0	450	7.40	5-6	201	0	0	7.24	10.96
5-6	504	15	70	7.82	9-10	731	60	555	7.28	9-10	1,016	45	500	6.68	6.12
9-10	620	15	95	7.78											
							F, New Jersey								
Original	655	60	100	6.59	1-2	738	45	150	7.07	1-2	267	0	T	6.64	3.32
1-2	599	15	160	6.65	5-6	902	90	550	7.12	5-6	3,485	90	2,250	5.65	4.17
5-6	691	30	180	6.46	9-10	1,727	344	1,900	5.15	9-10	4,738	495	3,150	5.13	20.79
9-10	1,296	180	740	5.95											
							G, Kentucky								
Original	464	45	75	6.12	1-2	968	0	375	6.64	1-2	624	0	275	6.25	5.01
1-2	459	15	100	6.52	5-6	1,549	60	850	5.95	5-6	1,419	90	870	5.73	7.72
5-6	558	0	140	6.43	9-10	2,527	225	1,625	5.22	9-10	4,593	570	3,045	4.71	24.70
9-10	936	75	320	5.86											
							H, Iowa								
Original	483	45	85	6.11	1-2	902	45	300	6.48	1-2	284	0	T	6.18	1.29
1-2	630	30	235	6.17	5-6	1,586	60	825	5.12	5-6	1,461	60	900	5.70	3.13
5-6	563	30	270	6.11	9-10	4,820	495	3,150	5.90	9-10	4,960	435	3,325	5.11	2.04
9-10	1,193	180	725	5.69											
							I, Texas								
Original	758	105	75	8.28	1-2	1,364	150	425	7.85	1-2	528	60	T	8.14	18.07
1-2	1,004	120	135	8.40	5-6	1,211	90	290	7.98	5-6	438	60	T	7.93	3.20
5-6	1,100	120	135	8.30	9-10	1,116	75	215	7.95	9-10	1,590	150	795	7.77	19.66
9-10	1,168	180	210	8.37											

*Total soluble salts. †Expressed in p.p.m.

The soil from Yuma responded indifferently to treatment the first year, but the second year brought significant responses in the pots receiving heavy applications of pyrite. The third year showed no decided increase or decrease in crop yields. The amount of copper in the treated plants is not appreciably higher than that in the control plants. No marked decrease in pH due to pyrite treatment is evident in the soil. The soil from Yuma was light and friable, and thus subject to leaching if over-watered. As a result some of the salts were leached from the soil, but in spite of this the sulfate content increased from 1,890 to 3,000 p.p.m.

TABLE 3.—*Effect of pyrite treatment upon crop yield.*

Soil	Treatment	Relative weight of straw and seed, check pots taken as 100		
		1925–26	1926–27	1927–28
Tumomoc Hill soil, A	1–4	100	100	100
	5–6	150	96	81
	7–8		101	91
	9–10	110	123	84
	11–12		99	74
University of Arizona soil, B	1–4	0	100*	100
			0	3
	5–6	0	110	98
	7–8		0	32
	9–10	0	134	64
	11–12		0	34
Yuma soil, C	1–4	100	100	100
	5–6	118	93	97
	7–8		220	123
	9–10	85	120	116
	11–12		248	105
Mesa soil, D	1–4	100	100	100
	5–6	79	77	75
	7–8		96	91
	9–10	85	92	96
	11–12		77	85
Oregon soil, E	1–2	100	100	100
	5–6	103	77	93
	9–10	120	79	66
New Jersey soil, F	1–2	100	100	100
	5–6	100	102	55
	9–10	101	89	49
Kentucky soil, G	1–2	100	100	100
	5–6	111	112	186
	9–10	128	101	86
Iowa soil, H	1–2	100	100	100
	5–6	97	101	94
	9–10	100	108	155
Texas soil, I	1–2	100	100	100
	5–6	124	107	112
	9–10	98	78	158

*Weight of sulfur-treated pot taken as 100.

Pyrite treatments had little effect on the Mesa soil. Here again, the lowering of the pH was found to be less than 1 pH unit. Leaching is responsible for a lowering, at the end of the third year, of both the SO_4 content and the total salt content

The Oregon soil was originally slightly alkaline (pH 7.70), but because of the lack of a large reserve of lime such as the Arizona soils contain its reaction was changed to slightly acid. The crop yields declined in the second and third year trials No large amounts of copper were present in any of the plants in this series, nor was the acidity of the soils so great as to be a limiting factor. The SO_4 content of the soil was raised from a trace to 500 p.p.m. and the total salt content from 455 to 1,016 p.p.m.

The soils from New Jersey and Kentucky responded similarly to the treatments. Crop yields on the heavily treated pots decreased the third year. Both were originally slightly acid and became extremely so by the end of the third year. The Jerome pyrite produced the greatest acidity The amount of copper found in the plants which had grown in the Jerome pyrite treated soils was high and inversely proportional to crop yields, but it is possible that the low pH of the soil was the cause of the poor plant growth the third year. The original total salt content of these soils at the beginning of the experiment was 655 and 464 p.p.m., respectively, but at the end was approximately 4,500 p.p.m., while the SO_4 content was over 3,000 p.p.m.

The Iowa soil gave indifferent responses to treatment the first two years, but the Jerome pyrite treated plants during the third year gave excellent responses. The pH apparently was not low enough to be a limiting factor, nor was a total soluble salt content of 4,960 p.p.m., or a SO_4 content of 3,325 p.p.m., toxic. The original total soluble salt content was 483 p.p.m. and the SO_4 content 85 p.p.m.

The Texas soil responded to the treatment in much the same way as did the Iowa soil, namely, favorable increases in crop yield for the pyrite-treated soils, the chief difference between the two being that the Texas soil had a pH above 7.0 while the Iowa soil was below 7.0. The SO_4 content was raised from 75 to 795 p.p.m.

It is quite evident that applications of pyrite from 2½ to 7 tons per acre will not lower the pH of Arizona soils appreciably, but that in neutral or slightly acid soils the resulting acidity may become a serious factor in crop production. In as much as the amount of pyrite used was unable to lower the acidity of the limestone-containing soils appreciably, it was decided to make a quantitative measurement of the amount of normal acid required to bring 20 grams of Yuma soil and 20 grams of Kentucky soil to a pH of 4.5. These soils were selected as being representative of the lime soils and acid soils used. The results are shown graphically in Fig. 1.

The acid soil is not highly impregnated with lime and, as a result, drops rapidly from a pH of 6.16 to a pH of 4.5 with the addition of small amounts of normal acid. The calcium carbonate in the lime soils is slowly broken down to CO_2 and H_2O with an accompanying lowering of the pH. The amount of acid required to bring the acidity of the lime soil to a pH of 4.5 is almost 90 times the amount required to lower the pH of the acid soil to the same point

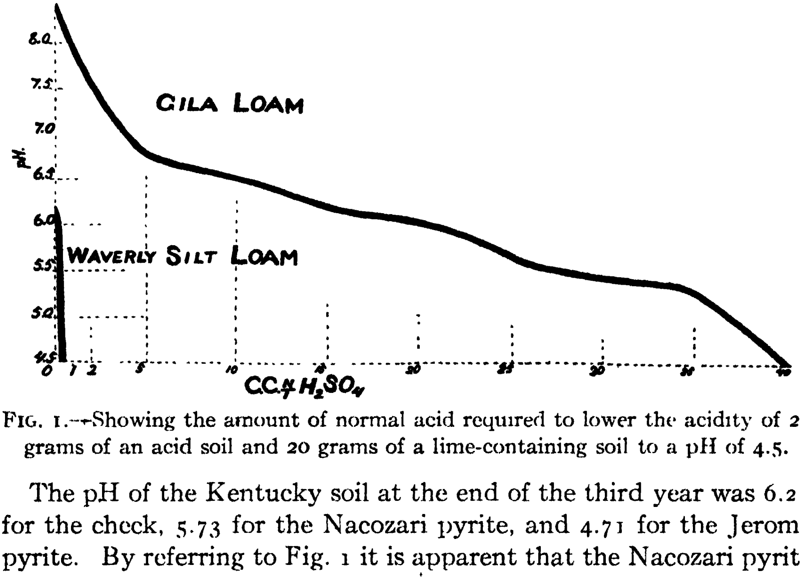

FIG. 1.—Showing the amount of normal acid required to lower the acidity of 20 grams of an acid soil and 20 grams of a lime-containing soil to a pH of 4.5.

The pH of the Kentucky soil at the end of the third year was 6.25 for the check, 5.73 for the Nacozari pyrite, and 4.71 for the Jerome pyrite. By referring to Fig. 1 it is apparent that the Nacozari pyrite lowered the pH, equivalent to 0.25 cc N H_2SO_4 for 20 grams of soil or 118.75 cc for 9.5 kgs, while the Jerome pyrite lowered it equivalent to 0.55 cc for 20 grams or 261.25 cc for the entire pot.

In the same way the amounts of Nacozari pyrite and the Jerome pyrite used in the heavy applications were found to be equivalent to 0.50 cc and 1.0 cc N H_2SO_4, respectively, in 20 grams of the lime soil, or 237.5 and 475.0 cc, respectively, for the 9.5 kgs of soil.

USE OF EXCESSIVE AMOUNTS OF PYRITE

When it became apparent that reasonable applications of pyrite would not become immediately effective on the black-alkali soils from the University Farm, another experiment was started in which extremely large amounts of pyrite were added. The soils selected for this experiment were (a) University of Arizona (old farm), representing a black-alkali soil; (b) Tumonoc Hill soil, representing an arid limestone soil; and (c) Yakima sandy loam from Oregon, representing a soil low in limestone. Pot experiments were run in duplicate with the following treatments, pots 1 and 2, check; pots 3 and 4, 2.5% Jerome pyrite; and pots 5 and 6, 5% Jerome pyrite. The black alkali soil from the University of Arizona old farm gave increased yields with treatment up to 5% pyrite during two years' trial. Yakima sandy loam gave decided crop decreases for either 2.5% or 5% pyrite treatment, while the Tumonoc Hill soil showed no harmful effects until more than 2.5% of pyrite had been added. The reasons for the above crop responses are evident when considered in the light of the chemical composition of the soil (Table 4).

A LETHAL AMOUNT OF COPPER

The copper applied with the pyrite in the first experiment was not present in sufficient amounts to retard crop growth. The heaviest applications of copper-carrying pyrite were equivalent to only 0.01% in the soil for the Nacozari pyrite and 0.008% of copper from the Jerome pyrite. If Jerome pyrite had been added as it was received from the United Verde Copper Company, only 0.006% of copper would have been added to the soil in the heaviest treatments, which would allow a still greater amount of pyrite to be added to soils without fear of copper toxicity Forbes (7), in a very thorough study of copper toxicity to plants, has shown that corn will withstand 0.08% of chalcocite (Cu_2S), but only 0 023% of the more soluble copper carbonate. In as much as the copper-carrying compounds used in this experiment were chalcopyrite ($CuFeS_2$) and chalcocite (Cu_2S), we would expect much the same tolerance as was found by Forbes, namely, 0 08%. The amount of copper applied to any soil in this experiment does not approach this figure.

SUMMARY

1. Soils varying widely in texture, in soluble salt content, and in reaction were studied to determine the rates of sulfur oxidation when copper-carrying pyrites (1.26 to 1.63% copper) and flowers of sulfur were used as sources of sulfur. By means of pot-culture experiments the effects of these substances on barley plants were noted.

2. Chemical analyses indicated an increase in the sulfate content of all soils, a decided lowering of the pH value of the acid soils, and little or no change in the pH of the alkaline soils.

TABLE 4.—*Chemical analyses of soils receiving 2.5 and 5.0%, respectively, of Jerome pyrite.**

Soil	Treatment	1926–27				1927–28			
		TSS†	Ca‡	SO_4‡	pH	TSS†	Ca‡	SO_4‡	pH
U. of A	1–2, check	2,361	15	T	10.10	1,583	0	T	9.90
	3–4, 2.5%	5,046	0	3,025	9.70	5,742	0	3,500	9.00
	5–6, 5.0%	6,818	15	4,015	9.40	5,342	15	3,150	8.71
Desert Laboratory	1–2, check	392	45	T	8.52	329	60	T	8.22
	3–4, 2.5%	2,882	375	1,760	8.12	3,460	420	2,375	7.65
	5–6, 5.0%	4,780	810	3,135	7.40	10,204	1,912	7,035	4.75
Kentucky	1–2, check	377	15	200	6.13	497	15	200	6.09
	3–4, 2.5%	2,189	240	1,415	5.19	8,628	825	6,050	3.50
	5–6, 5.0%	2,712	315	1,760	5.10	5,633	105	3,685	3.95

*2.5% of Jerome pyrite and 8.0 kgs soil = 0.0296% cu. in. soil; 5.0% Jerome pyrite and 8.0 kgs soil = 0.0592% cu. in. soil.

†Total soluble salts in p.p.m.

‡In p.p.m.

3. Observations and analyses of the crops did not indicate copper toxicity with the amounts of pyrite used.

4. Chemical analyses of the soils indicated the production of too high concentrations of soluble salts in certain soils for best growth.

5. Determinations of pH on the soils indicated conditions too acid for optimum plant growth in soils not originally well supplied with lime.

6. Experiments both in the laboratory and in the screen garden showed that the sulfur in Jerome pyrite and in Nacozari pyrite was capable of fairly rapid oxidation to sulfate.

7. Pyrite, carrying small amounts of copper, may be safely applied to calcareous soils in fairly large amounts. Acid soils should be treated with care, unless lime also is used.

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"DRY INOCULANTS" FOR ALFALFA[1]

WM. A. ALBRECHT[2]

The more extensive production of bacterial cultures for inoculating purposes has recently brought forth dry cultures with claims that legumes can be inoculated without the use of any moisture. This dry inoculation has been extolled for (a) its simplicity, since it is a fine powder which needs only to be mixed with, or sifted on, the dry seed; and (b) for its positivity, with the claims that the inoculation procedure may be carried out at any time irrespective of the seeding date. Since bacteria retain their inoculating ability for a long time in dry soil,[3] one may readily infer that these dry materials might serve for inoculating purposes. The questions arise, however, whether such dry mixing distributes the culture into the soil effectively, and whether the small amount of dry, bacteria-laden material so distributed with the seed really serves to produce significant nodulation.

A test was recently conducted on two different dry inoculants for alfalfa, submitted by a commercial seed house, questioning whether such an inoculant would serve, and whether the seed might be inoculated and sold as such by the extensive seed distributor. One of the cultures tested was an air-dry, chamois-gray, pulverized material, suggesting dry soil. The other culture was a black-gray material of peaty nature carrying carbonate. These carried the instructions for mixing with the seed as received, leaving both seed and inoculant in the dry condition. Such dry inoculated seed is supposedly ready to be seeded or may be stored for a long time with good results.

Alfalfa seed was inoculated with these commercial dry inoculants for comparison with seed inoculated by agar cultures in the first sample and by both agar cultures and soil-crushed-nodule suspension in case of the second sample. The following scheme was used: 1, no inoculation; 2, dry culture mixed with dry seed as directed; 3, dry culture sifted on the moistened seed and mixed; 4, dry culture made up with water, using "dirty" supernatant liquid only; 5, dry culture sifted on the moistened seed, mixed, and followed by a dusting of finely powered limestone; 6, commercial agar culture applied to the seed; 7, commercial agar culture applied to seed and supplemented by a dusting of finely powdered limestone; 8, soil-crushed-nodule suspension applied to seed; and 9, soil-crushed-nodule sus-

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[1] Contribution from the Department of Soils, University of Missouri, Columbia, Mo. Received for publication May 26, 1930.

[2] Associate Professor.

[3] ALBRECHT, WM. A., and TURK, LLOYD M. Legume bacteria with reference to light and longevity. Mo. Agr. Exp. Sta. Res. Bul. 132. 1930.

TABLE 1.—*Nodule numbers and percentage of inoculation of alfalfa by dry inoculants.*

	Inoculant No. 1, Shelby loam					Inoculant No. 2				
						Shelby loam		Lindley loam		
	Test No. 1		Test No. 2							
	Nodules per plant	Inoculation %	Nodules per plant	Inoculation %	Average No of nodules all plants	Nodules per plant	Inoculation %	Nodules per plant	Inoculation %	Average No. of nodules all plants
Check	3.8	68	8.4	100	5.9	0.44	36	0.08	8	0.26
Dry culture .	5.8	88	10.2	100	8.4	0.64	44	0.48	24	0.56
Dry culture in water, using water only .	9.2	100	12.7	100	11.2	2.5	52	0.32	28	1.42
Dry culture on moist seed	9.3	100	13.6	100	11.4	0.28	20	0.08	8	0.18
Dry culture on moist seed, limestone	11.5	100	15.9	100	14.2	0.76	52	0.84	32	0.80
Agar culture	10.4	100	26.8	100	18.2	5.2	100	0.92	48	3.0
Agar culture plus limestone	23.2	100	28.7	100	25.7	6.8	96	4.8	92	5.8
Soil nodule suspension						7.8	100	1.7	68	4.7
Soil nodule suspension, limestone						7.8	100	2.5	92	5.1

pension applied to the seed and supplemented by a dusting of finely powdered limestone.

The seeds so inoculated were seeded as separate rows. For the first inoculant tested, a neutral soil of moderate fertility and excellent structure was used. This soil was of the Shelby loam type, taken from a small area of moderate slope, grown to soybeans for the past three years but not grown to alfalfa or sweet clover within recent knowledge. For the test of the second inoculant, this same soil was supplemented by one which is subject to overflow, neutral, and near a sweet clover crop (Huntington loam), and by a sour soil of very poor fertility away from chance contamination by these crops (Lindley loam).

The plants for all the different treatments were grown for 10 weeks. At the end of that period the plants from each treatment were taken up, the soil carefully washed from the roots, and nodule counts made on as many as 25 plants per treatment. The results are given in Table 1. Since the Huntington loam was thoroughly inoculated naturally, all treatments were uniformly well nodulated and the data are not included in the table.

It is evident from the data that in none of the methods of using these dry inoculants were the nodule numbers on the alfalfa roots increased over the check to the same extent as was true for the commercial agar culture or for the soil culture. The use of water in connection with the dry culture favored nodule production in some of the trials. The use of the limestone in connection with the agar cultures improved inoculation on all soils except on the Huntington loam, but this effect by lime was not significant on the dry inoculants.

A portion of the dry inoculated seed in the first test was stored and planted 10 days later. This gave nodule production no greater than the uninoculated seed. For this planting the inoculated seed was taken out of the top of the storage container as it had been left for 10 days, but in no wise given significant handling. The nodule production by the use of the dry culture was so low both with and without storage that it is questionable whether much significance can be attributed to the storage as it reduced the nodule numbers.

From these trials of two dry inoculants on alfalfa there arises doubt as to whether these cultures can serve to increase nodule numbers significantly. The nodulation resulting from this method under these trials was by no means equal to that from agar cultures or soil cultures and scarcely greater than that which occurred by chance. Further trials of these cultures from various sources will be necessary to establish their value fully. These preliminary trials of dry inoculants suggest, however, the danger of getting ease of manipulation at the cost of efficiency in nodule production.

NORMAL MAGNESIUM CARBONATE IN COMPARISON WITH "LIGHT" AND "HEAVY" OXIDES AND CARBONATES IN THE SOIL[1]

W. H. MacIntire and W. M. Shaw[2]

Many comparisons have been made between the effects of precipitated carbonates of calcium and magnesium in soil In such comparisons the hydrated carbonate of magnesium, $3\ MgCO_3.Mg(OH)_2.3H_2O$, has been most frequently used Basic, or precipitated, magnesium carbonate is to be had in the two forms, "light" and "heavy". These two materials possess distinctive physical properties. Moreover, when the "light" and "heavy" types of carbonates are "calcined" they yield the "light" and "heavy" oxides No published comparison of these four forms is to be found. There are also two crystalline, *hydroxide-free*, carbonates that have not been used in any soil studies known to us

In certain previous outdoor lysimeter experiments, relative to the silication of calcium and magnesium, excessive quantities of seven liming materials were added. From computations made some years later to obtain a balance between the outgo and the residue of precipitated magnesium carbonate, it appeared that the $MgCO_3$-$Mg(OH)_2$ relationship in the unabsorbed and unleached excess was close to that which existed in the added precipitated carbonate, in spite of its extended contact with carbonated-water solutions that had removed large quantities of magnesium bicarbonate in the leachings. An adjunct lysimeter project was therefore inaugurated for the further study of the outgo and the fixation of magnesium from five oxides and carbonates

This paper deals with the variations in chemical and biochemical activities induced by the several materials and with the balance found between additions and outgo at the end of a 4-year period The problem of the nature of the fixation processes and products will be considered separately.

EXPERIMENTAL

A brown loam soil of the Hagerstown series was used without subsoil in nine 1/20,000-acre tanks. The soil had been in sod for a long period of years. This fact is reflected in the larger amounts of bases that were leached, in comparison with the losses found for the same soil after years of cultivation. The grass sod was skimmed off and discarded. The soil in the tanks was kept fallow during the 4 years of the experiment.

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[1] Contribution from the Department of Chemistry, University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication May 22, 1930.

[2] Head of Department and Associate Soil Chemist, respectively.

The five magnesic materials used were "light" and "heavy" oxides, "light" and heavy" precipitated carbonates, and normal, or crystalline, carbonate. The CaO-equivalent titration values of these five materials were 115.9, 121.2, 56.56, 56.84, and 40.27%, respectively. Each addition was mixed throughout the full 8-inch depth of soil. The $Mg(OH)_2$-free, crystalline magnesium carbonate had the composition $MgCO_3.3H_2O$, or that which is found for the crystals that form following the spontaneous loss of CO_2 from magnesium bicarbonate solutions at room temperature. The "light" and "heavy" oxides were compared with "light" and "heavy" carbonates and crystalline $MgCO_3$ at the CaO-equivalent rate of 8 tons per 2,000,000 pounds of soil, or 1.429% $CaCO_3$. The "light" oxide, "light" carbonate, and crystalline carbonate were also used at the rate of 32 tons CaO-equivalence, or 5.714% $CaCO_3$-equivalence, so as to insure an excess of unabsorbed carbonate

The separate percolates from natural rainfall were analyzed for carbonate-bicarbonate and nitrate content. The annual composites of percolates were analyzed to determine the outgo of calcium, magnesium, potassium, and sulfates. Residual carbonates were also determined.

MAGNESIUM OUTGO

The annual and total leachings of magnesium are given in Table 1. In this and subsequent tables the losses of calcium and magnesium are expressed as pounds $CaCO_3$-equivalence per 2,000,000 pounds of soil. The cumulative losses are given graphically in Fig. 1, in which the losses from the four oxides and precipitated carbonates are averaged for comparison with the loss from the crystalline carbonate at the 8-ton rate Individual values are given for the three forms at the 32-ton rate.

The losses from the two 8-ton oxide additions were comparable as totals, although the outgo from the heavy form was the greater during each of the first three years. The same relationship held for the two equivalent additions of the two hydroxy carbonates. The total magnesium outgo from the "light" oxide was almost equal to that obtained from the "light" carbonate. This approximation was found even during the initial year. A similar relationship was demonstrated for the "heavy" oxide and the "heavy" carbonate. This may be explained by the fact that the meager solubility of the hydrated oxide of magnesium permits the formation and outgo of large quantities of magnesium bicarbonate from a system that still contains considerable quantities of uncarbonated magnesium hydroxide. A large part of the magnesium outgo from the 8-ton carbonate additions was derived from that which had been fixed by the soil. All of the losses after the first year are to be attributed to absorbed magnesium, for related studies (7)[3] had shown that an extensive silication, or fixation, of the magnesic additions had occurred within a short period.

TABLE 1.—*Magnesium outgo from magnesic additions.*

Magnesic additions		$CaCo_3$≎ pounds per 2,000,000 pounds of soil				
Form	CaO≎ in tons	1st year	2d year	3d year	4th year	4-year total
Control . .	—	252	291	182	213	938
"Light" Magnesia.	8	6,768	2,868	2,335	1,782	13,753
"Heavy" Magnesia	8	7,125	2,896	2,405	1,680	14,106
"Light" Magnesia carbonate	8	6,896	2,760	2,463	1,791	13,910
"Heavy" Mg. carbonate....	8	7,486	3,229	2,757	1,783	15,255
Crystalline Mg. carbonate...	8	10,004	2,976	2,155	1,552	16,687
"Light" Magnesia.	32	6,543	8,843	7,945	7,173	30,504
"Light" Mg. carbonate.	32	7,694	6,076	5,794	5,820	25,384
Crystalline Mg. carbonate.	32	16,238	12,937	8,098	7,548	44,821

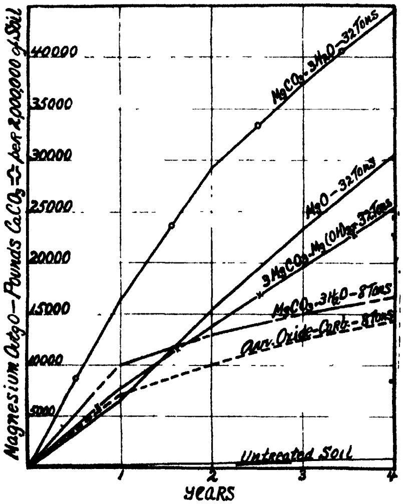

FIG. 1.—The outgo of magnesium from "light" and "heavy" oxides and precipitated carbonates and the normal carbonate of magnesium, at two rates of addition.

During the initial year, the outgo from the 8-ton addition of crystalline carbonate was materially greater than that from either of the four oxide and precipitated carbonate materials. Since the crystalline carbonate showed the smallest amount of residual magnesium at the end of the first year, its outgo thereafter was more in accord with the losses from the other four materials. The 4-year total from the crystalline compound was still considerably greater, however, than that from either of the other four treatments. The magnesium outgo from 8 tons of the crystalline carbonate during the initial year was 2,318 pounds, or 30% greater than that from the four-fold addition of the "light" hydroxy carbonate.

[3] Reference by number is to "Literature Cited," p. 934.

In the case of the 32-ton additions, each unabsorbed fraction evidently furnished the magnesium outgo and thus protected the absorbed fraction against hydrolysis and depletion. The crystalline form demonstrated its greater solubility in the free soil-water in that it yielded an outgo of magnesium carbonate decidedly in excess of that from the "light" carbonate for each annual period. This was especially true during the first two years, the outgo from the crystalline carbonate during that period being 2.12 times that from the "light" carbonate. The outgo from the "light" oxide was only 15% less than that from the "light" carbonate during the initial year. During the next 3 years, however, the losses from the oxide were decidedly larger than those from the "light" carbonate. Hence, the total outgo from the 32-ton addition of "light" magnesium oxide was 5,120 pounds in excess of that from the equivalent addition of "light" carbonate—$3MgCO_3.Mg(OH)_2$. The order of total magnesium losses was 100 for the maximum outgo from the crystalline compound, 68 for the "light" oxide, and 57 for the "light" carbonate.

It would be expected that the outgo of magnesium from the carbonate forms would be greatest during the initial year The amounts then present are greatest and the most marked acceleration of bacterial activities is also noted during the first year. Furthermore, the extensive fixation of magnesium by the acid silicates is accompanied by a liberation of CO_2 and the free soil-water is thus enriched with CO_2 so that the solid-phase residues are more readily dissolved. The greater solubility of the crystalline carbonate is further accounted for by the generation of magnesium bicarbonate that accompanies the hydrolytic breakdown of the magnesium carbonate in solutions with low CO_2 tensions. According to Johnston (2), $MgCO_3.3H_2O$ is to be found as the solid phase in equilibrium with its solution at a CO_2 pressure of 0 00037 at 18° C. The greater outgo of magnesium bicarbonate results in an accumulation of the hydroxy carbonate as represented by the equation: $5MgCO_3+2H_2O \longrightarrow 3MgCO_3.Mg(OH)_2+MgH_2(CO_3)_2$.

CALCIUM OUTGO

The losses of calcium are given in Table 2 and shown cumulatively by the curves of Fig. 2. It has been pointed out that the soil had been in sod for a long time. The resultant accumulation of available forms of calcium, therefore, gave calcium leachings far in excess of those found for the same soil after it had been under cultivation.

The natural calcium silicates were protected against hydrolysis by each magnesic addition. Each calcium outgo was therefore less than that obtained from the untreated soil during each annual period. The

TABLE 2.—*The influence of magnesic additions upon the outgo of calcium.*

Magnesic additions Form	CaO⇔ in tons	$CaCO_3$⇔outgo, pounds per 2,000,000 pounds of soil 1st year	2d year	3d year	4th year	4-year total
Control	—	497	596	445	465	2,003
"Light" Magnesia	8	311	198	336	293	1,138
"Heavy" Magnesia	8	246	220	316	246	1,028
"Light" Mg. carbonate	8	317	226	302	239	1,084
"Heavy" Mg. carbonate	8	288	192	275	226	981
Crystalline Mg. carbonate	8	291	213	311	240	1,055
"Light" Magnesia	32	261	89	119	83	552
"Light" Mg. carbonate	32	261	138	180	146	725
Crystalline Mg. carbonate	32	276	101	136	101	614

average total for the five 8-ton additions amounted to only 53% of that obtained from the untreated soil. The 32-ton additions were still more repressive and gave an average calcium outgo of only 31.5% of that yielded by the untreated soil. This depressive effect of magnesium upon calcium outgo is in harmony with previous findings at this Station relative to the "reciprocal repression" (6, 12, 13) exerted by high-calcic and high-magnesic additions. If the results obtained by Leather and Sen (4), in systems devoid of soils be applied, it seems that, with solutions containing the amounts of magnesium bicarbonate found in the percolates, the diminished outgo of calcium was leached in forms other than calcium bicarbonate. On the other hand, the findings of Bothamley (1) indicate that soluble neutral salts of calcium would not be present in solutions that carry a high concentration of magnesium salts with low CO_2 pressure.

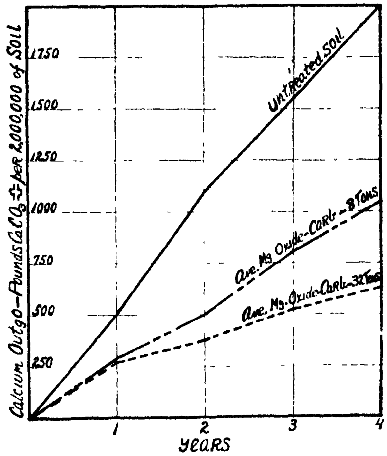

FIG. 2. The repressive effect of magnesic additions upon the outgo of calcium.

CALCIUM AND MAGNESIUM OUTGO

The diminished outgo of calcium and computations of bicarbonates necessitate the treatment of the combined totals of calcium and magnesium which are given in Table 3. These totals are compared with the total dissolved carbonates and bicarbonates in Table 4.

TABLE 3.—*Calcium+magnesium outgo from magnesic additions.*

Magnesic additions		Pounds CaCO$_3$≎ per 2,000,000 pounds of soil				
Form	CaO≎ in tons	1st year	2d year	3d year	4th year	4-year total
Control	—	749	887	627	678	2,941
"Light" Magnesia	8	7,079	3,066	2,671	2,075	14,891
"Heavy" Magnesia	8	7,371	3,116	2,721	1,926	15,134
"Light" Mg. carbonate	8	7,213	2,986	2,765	2,030	14,994
"Heavy" Mg. carbonate	8	7,774	3,421	3,032	2,009	16,236
Crystalline Mg. carbonate	8	10,295	3,189	2,466	1,792	17,742
"Light" Magnesia	32	6,804	8,932	8,064	7,256	31,056
"Light" Mg. carbonate	32	7,955	6,214	5,974	5,966	26,109
Crystalline Mg. carbonate	32	16,514	13,038	8,234	7,649	45,435

CARBONATE-BICARBONATE OUTGO

The titration-equivalent from the carbonate-free soil control shows that its native non-carbonate components have supplied a CaCO$_3$-equivalence of 14.7% of its Ca+Mg outgo. The sodium and potassium leachings are negligible; hence this CaCO$_3$-equivalence was necessarily derived from the hydrolysis of native calcic and magnesic complexes, either directly or through plant residues, since the soil contained no CaCO$_3$.

In agreement with the losses of magnesium, the bicarbonate totals from the "light" and "heavy" oxides and carbonates do not vary widely for the 8-ton additions, although the percolates from each "heavy" form gave a titration value slightly more than that from the corresponding "light" material. In harmony with the total magnesium outgo, the bicarbonate yield from the crystalline carbonate was considerably greater than the losses from the other 8-ton additions.

During each annual period the maximum bicarbonate outgo came from the 32-ton crystalline carbonate addition. The actual total amounts of bicarbonates, *viz.*, 38,812, 25,854, and 21,139 pounds, represent 85.4, 83.2, and 81% of the Ca+Mg totals from the crystalline carbonate, "light" oxide, and "light" carbonate, respectively. The 32-ton addition of "light" MgO extracted, from the soil and aerial atmospheres, 11,376 pounds of CO$_2$ to effect the carbonation of the amount of oxide that leached out in the carbonate-bicarbonate forms. The total outgo of CO$_2$ would be twice that amount, if all of the titrated alkalinity were due to magnesium bicarbonate.

Were the full titration-equivalences of the percolates from the two 32-ton carbonate additions attributable to bicarbonates, there would be 18,077 pounds and 9,301 pounds of dissolved, or free, CO$_2$ carried

TABLE 4.—*$CaCO_3$-equivalence of carbonates and bi-carbonates removed in percolates from magnesic additions.*

Magnesic additions		Pounds $CaCO_3$≎ per 2,000,000 pounds of soil									
		First year		Second year		Third Year		Fourth year		4-year total	
Form	CaO≎ in tons	Actual	As % of total	Actual	As % of total	Actual	As % of total	Actual	As % of total	Actual	As % of total
Control	—	111	14.8	99	11.2	110	17.5	111	16.4	431	14.7
"Light" Magnesia	8	5,064	71.5	2.073	67.6	1,745	65.3	1,107	53.3	9,989	67.1
"Heavy" Magnesia	8	5,705	77.4	2.167	69.5	1,766	64.9	998	51.8	10,636	70.3
"Light" Mg. carbonate	8	5,229	72.5	2,327	78.0	1,776	63.9	1,052	51.8	10,384	69.3
"Heavy" Mg. carbonate	8	5,992	77.1	2,461	71.9	1,840	60.7	758	37.7	11,051	68.1
Crystalline Mg. carbonate	8	8,998	87.4	2,279	71.5	1,575	63.9	892	49.8	13,744	77.5
"Light" Magnesia	32	5,885	86.5	7,980	89.3	7,006	86.9	4,983	68.7	25,854	83.2
"Light" Mg. carbonate	32	7,083	89.0	5,002	80.5	4,909	82.2	4,145	69.5	21,139	81.0
Crystalline Mg. carbonate	32	14,466	87.6	11,936	91.5	7,095	86.2	5,315	68.7	38,812	85.4

out by the percolates from the crystalline and "light" carbonates, respectively. But, when the percolate accumulations are analyzed periodically, there is never found an exact equilibrium between $MgCO_3$ and the dissolved CO_2. The quantity of gaseous CO_2 present in the percolates from the heavy additions is always insufficient to prevent indications of alkalinity by phenolphthalein; hence, the dissolved CO_2 approximates, but cannot be considered as equal to, the two amounts of fixed CO_2, 18,077 pounds and 9,301 pounds, respectively.

In spite of the liberation of CO_2 that occurs when the magnesium of the precipitated carbonate is fixed by the soil, the 32-ton hydroxy carbonate, containing only 1 mole of $Mg(OH)_2$ to 3 moles of $MgCO_3$, yielded an outgo of carbonate-bicarbonate, and also a total magnesium outgo, that was less than the corresponding quantities obtained from the magnesium oxide. It might be suggested that the solubility of the precipitated carbonate was responsible for a depression in the activities of CO_2-generating organisms, and that the sparingly soluble oxide did not cause such a depression. But the equivalent addition of the more soluble crystalline carbonate was dissolved even more readily and gave the maximum outgo of both magnesium and bicarbonates for each annual period. It is true that the crystalline material could not be so thoroughly disseminated throughout the soil mass as was the pulverulent fluffy carbonate. Hence, the action of the crystalline particles may have been somewhat localized. Furthermore, as it has been pointed out, the crystalline carbonate produces its own supply of magnesium bicarbonate and thus is not dependent upon the free CO_2 that is derived from bacterial activities and the fixation process. The sum total of the several factors caused the heavy addition of the crystalline carbonate to carry the maximum amount of free CO_2 from the soil.

RESIDUAL CARBONATES

The residual carbonate determinations, made on 50-gram charges at the end of the 4 years of exposure, are given in terms of $CaCO_3$-equivalence in Table 5.

The small percentage shown for the untreated soil is the equivalent of 0.0055 gram CO_2, an amount that is several times that of the meager blank found for manipulation when the original acid soil is not included. The CO_2 evolution at room temperature is considered as having come from the organic matter content of the soil rather than from any supply of carbonates in the acid soil. Oxidation, as a consequence of the generation of nascent chlorine through reaction between the hydrochloric acid and oxides of manganese, is one possible explanation for the unfailing and continued evolution of CO_2 from the soil blank.

TABLE 5.—*Residual carbonate and total magnesium residues from magnesic additions.**

Magnesic additions		Carbonate CO_2		Magnesium as $CaCO_3$≎		
Form	Tons†	Actual	$CaCO_3$≎	Added	Leached	Remaining
None...	—	0.011	0.025	——	0.047	——
"Light" MgO..	8	0.033	0.075	1.429	0.688	0 741
"Heavy" MgO	8	0.028	0.062	1.429	0.705	0.724
"Light" Mg. carbonate ..	8	0.028	0.062	1.429	0.696	0.733
"Heavy" Mg. carbonate .	8	0.033	0.075	1.429	0.763	0.666
"Normal" Mg. carbonate	8	0.033	0.075	1.429	0.835	0.594
"Light" MgO . . .	32	0.264	0.599	5.714	1.526	4.188
"Light" Mg. carbonate.	32	0.856	1.942	5.714	1.269	4.445
"Normal" Mg. carbonate	32	0.478	1.086	5.714	2.242	3.472

*A.O.A.C. method, 50-gram charges with 75 cc 1+9 HCl, modified by aspiration for 1½ hours.

†CaO-equivalent.

The consistent quantities of carbonate CO_2 obtained from the 8-ton additions after 4 years correspond to those previously found for precipitated magnesium carbonate before the end of the first year, and even within a few weeks (8). The increases over the control are probably not due to unassimilated particles of the original materials, as may be the case with burnt lime additions. The greater solubility of the magnesic materials would militate against the occurrences of residual carbonate particles. On the other hand, the readily hydrolyzed magnesium-absorption complex insures the presence of considerable quantities of magnesium bicarbonate in the free soil water. When the soil is dried for analysis, magnesium carbonate is therefore deposited. This deposition is considered as explaining the small uniform quantities of residual carbonates found in the analyses of the 8-ton group.

In connection with the fact that the 32-ton addition of magnesium oxide showed a smaller carbonate residue than did the "light" carbonate, it should be recalled that the magnesium outgo from the oxide was also greater than that from the light carbonate. Of the added MgO, 4.188% still remained, and of this, 0.599% was present as carbonate, leaving 3.589% to be accounted for. If from this amount there be subtracted the fixation of 0.741% that was found for the 8-ton addition, it means that 2.848% was still present as the uncarbonated MgO, or $Mg(OH)_2$. The fixation induced by the 32-ton MgO addition was undoubtedly somewhat greater than that found for the 8-ton addition, but certainly not four times as great. Hence the remaining 4.188% is to be accounted for jointly by the two factors—greater fixation and incomplete carbonation of the residual MgO.

The largest carbonate residue from the 32-ton additions was due to the "light" carbonate, and this addition also gave the smallest outgo of both total magnesium and total bicarbonates. The difference between the total residual of magnesium and that accounted for by carbonates was 2 503% To postulate that all of the residual from the added $3MgCO_3.Mg(OH)_2$ had been converted to $MgCO_3$, it would be necessary, therefore, to assume a fixation of 2.503% or 3.42 times that which was found for the 8-ton addition of "light" carbonate. This is untenable, and it must be concluded that the residual 4.445% is to be accounted for jointly by a persistence of the hydroxy form and a greater fixation than that found for the 8-ton addition of "light" carbonate, $3MgCO_3.Mg(OH)_2$.

There was a residual occurrence of 3.472% from the normal carbonate, and this was the smallest quantity remaining from the three 32-ton additions. Of this, 1.086% was accounted for by the carbonate-equivalence of the determined carbonate-CO_2, leaving 2.386% to be accounted for. This amount, 2.386%, is equivalent to 4.01 times the amount that was fixed from the 8-ton addition of normal carbonate and is far in excess of the base-unsaturation coefficient of the original soil. It is evident, therefore, that the normal carbonate was not stable under the partial pressure of CO_2 that prevailed in the soil system and that some of the excess of the added normal carbonate had disintegrated into an hydroxy carbonate, or carbonates of magnesium. This would conform to the computations of Johnston (2) for aqueous systems of low CO_2 pressure. He found that when in equilibrium with the solution, "the solid phase was $MgCO_3.3H_2O$ at pressures above 0.00037, but $Mg(OH)_2$ when the pressure of CO_2 is less than 0.00037". This also harmonizes with the contention of Seyler and Lloyd (14) that the crystalline carbonate has no definite solubility coefficient in water, in which it breaks down into basic carbonates and bicarbonate. They state, "The larger the amount of carbonate in relation to the water, the larger is the amount of dissolved hydrogen carbonate, but the carbonate tends to reach a limit". The breakdown would therefore be greater during the wet winter months, when the soil water contains the minimum of dissolved CO_2. In the soil, an excess of the solid crystalline carbonate is subject to periodic solution and deposition; hence, the formation of the magnesium hydroxide would be cumulative.

INFLUENCE ON POTASH SOLUBILITY

The determination of the outgo of potassium for each annual period is given in Table 6. It should be stressed that an accumulation of more soluble forms of potash had occurred during the years that the soil had remained in sod and that the outgo of potash greatly exceeded that found for the same soil after years of cropping.

TABLE 6.—*The influence of magnesic additions upon the outgo of potash.*

Magnesic additions		Pounds K_2O per 2,000,000 pounds of soil				
Form	CaO≎ in tons	1st year	2d year	3d year	4th year	4-year total
Control .	—	70	74	42	52	238
"Light" Magnesia.	8	51	44	37	38	170
"Heavy" Magnesia .	8	56	42	31	42	171
"Light" Mg. carbonate	8	39	44	28	39	150
"Heavy" Mg. carbonate	8	59	40	32	41	172
Crystalline Mg. carbonate	8	68	40	27	40	175
"Light" Magnesia	32	68	30	26	34	158
"Light" Mg. carbonate. .	32	57	32	19	28	136
Crystalline Mg. carbonate	32	51	37	16	34	138

It is evident that every addition of magnesia exerted a repressive effect upon the outgo of the potash from this soil, which contained unusual stores of the more available forms of potash, because of accumulations from a permanent sod. The results from four of the 8-ton additions were practically identical, whereas the fifth addition, "light" magnesium carbonate, showed a greater repressive effect.

Each 32-ton addition induced a potash repression greater than that found for its corresponding form at the 8-ton rate. The respective averages for potash outgo from the 8-ton and 32-ton additions were 165 pounds and 144 pounds, whereas the outgo from the untreated soil was 238 pounds.

SULFATE OUTGO

Each magnesic addition caused a material increase in sulfate outgo, as shown in Table 7. This enhancement was especially marked during the first annual period. The totals for the 4-year period are comparable for seven of the eight additions. The largest outgo came from the 8-ton addition of "heavy" carbonate. The accelerative tendency that excessive amounts of magnesic materials exert on sulfofication, as measured by the leaching of sulfates, and the reverse effect induced by CaO, have been previously pointed out (9, 10, 11).

TABLE 7.—*The influence of magnesic additions upon the outgo of sulfates.*

Magnesic additions Form	CaO≎ in tons	Pounds SO_3 per 2,000,000 pounds of soil 1st year	2d year	3d year	4th year	4-year total
Control	—	144	161	152	136	593
"Light" Magnesia	8	344	181	191	167	883
"Heavy" Magnesia	8	318	181	190	168	857
"Light" Mg. carbonate	8	335	156	186	176	853
"Heavy" Mg. carbonate	8	416	180	184	167	947
Crystalline Mg. carbonate	8	361	187	180	156	884
"Light" Magnesia	32	395	160	156	125	836
"Light" Mg. carbonate	32	367	188	151	150	856
Crystalline Mg carbonate	32	381	178	167	131	857

NITRATE NITROGEN OUTGO

The losses of nitrate nitrogen are given in Table 8. The results could not well be compared with short-period pot and laboratory nitrification studies such as those of Kelley (3), since the soils in the lysimeters were subjected to the influence of weather, including the removal of nitrates throughout the 4-year period. The four 8-ton additions of "light" and "heavy" oxides and carbonates caused a large increase in nitrate outgo, especially during the initial year. The two precipitated carbonates produced a more marked effect than their corresponding oxides. On the other hand, the total nitrate outgo induced by the crystalline carbonate was somewhat less than that derived from the untreated soil.

TABLE 8.—*The influence of magnesic additions upon the outgo of nitrate nitrogen.*

Magnesic additions Form	CaO≎ in tons	Pounds N per 2,000,000 pounds of soil 1st year	2d year	3d year	4th year	4-year total
Control	—	116	149	119	91	475
"Light" Magnesia	8	160	159	134	101	554
"Heavy" Magnesia	8	181	191	118	98	588
"Light" Mg. carbonate	8	255	185	126	102	668
"Heavy" Mg. carbonate	8	259	206	121	93	679
Crystalline Mg carbonate	8	122	152	108	82	464
"Light" Magnesia	32	17	111	121	61	310
"Light" Mg. carbonate	32	54	141	93	73	361
Crystalline Mg. carbonate	32	58	96	116	68	338

All of the 32-ton additions caused a distinct decrease in nitrate outgo. This repressive effect upon nitrification was especially marked during the initial year. It is evident that nitrification was accelerated by the two oxides and by both of the basic carbonates at one rate and repressed at the other, whereas the crystalline form failed to accelerate nitrification at the 8-ton rate and depressed it markedly at the higher rate of 32 tons.

APPLICATION TO LIME-MAGNESIA RATIO STUDIES

In studies on the problem of calcium-magnesium relationships, especial emphasis has been placed on the properties of the added materials *outside* of the soil. This is permissible in sand cultures, which do not effect fixation, but it is not for soils. When moderate treatments are given, so that the full addition becomes fixed in the soil, the properties of the absorption compounds are the paramount consideration. Absorbed calcium and absorbed magnesium impart distinctive properties to a soil system, and it appears that the relationship is the reverse of that which is to be found for the two elements as they occur in mineral silicates.

At the time that Loew (5) gave a digest of his earlier studies and those of his students and critics it was not known that the action of absorbed calcium and magnesium would be "reciprocally repressive", nor that both elements would decrease the solubility of potash. Loew therefore treated the ratio problem as being solved by increasing the amount of the element that was deemed inadequate, without considering the intra relationships. But when calcium is added to increase the ratio of calcium to magnesium there results an actual depression of the amount of magnesium offered to the plant. In the same manner, and to a much more marked extent, the addition of a caustic, or a carbonate, form of magnesium enriches the soil in available magnesium, but it diminishes the amount of available calcium below that found for the untreated soil. This is brought out by the data of Table 2 and is shown graphically in the cumulative curves of Fig. 2.

Furthermore, the simultaneous addition of calcium and magnesium by means of dolomite does not result in an enrichment of both elements in the free soil water after the dolomite has been absorbed (7). Only an enhancement in magnesium is then to be found. When dolomite is used there is found the same repression in potash solubility that occurs when lime or magnesia is used singly. It is thus evident that addition of different forms of calcium or magnesium will produce one uniform result—decrease in potash availability—together with a distinct variable as to calcium and magnesium relationships.

If, on the other hand, additions of calcium and magnesium carbonates are made beyond the absorptive capacity of the soil there arises another set of conditions. The absorption capacity of a soil for a carbonate is not a constant, but varies with the element and its form. The absorption of magnesium is not the same for the hydrated carbonates, crystalline carbonate, magnesite, and dolomite. Hence, when excessive additions of carbonates are made, the composition of the soil solution is governed by the carbonate excess, rather than the components of the soil systems. The influence exerted by excesses of magnesium carbonate in effecting a precipitation of dissolved $CaCO_3$, or in preventing its entrance into solution, thereby causing a paucity of magnesium in ratio studies, has been suggested by Leather and Sen (4). They did not work with soils, but they applied their findings by stating, "Indirectly this investigation offers some explanation of the somewhat contradictory results which have been obtained at experiment stations in different countries regarding the lime-magnesia ratios in soils,* * * but where magnesium carbonate has been employed in any large quantity its presence in the soil might easily reduce the solubility of calcium carbonate sufficiently to cause 'lime-starvation' ". Our own investigations have shown that this effect is likewise encountered in the absence of solid-phase carbonates, for ordinary additions of magnesium oxide and carbonate continue to exert this repressive effect upon the native calcium of the soil long after the added magnesium has been absorbed by the soil.

SUMMARY

A comparison of five magnesic materials—"light" and "heavy" oxides, "light" and "heavy" precipitated carbonates, and a crystalline carbonate, $MgCO_3.3H_2O$—at 8-ton and 32-ton CaO-equivalent rates was conducted in a 4-year lysimeter experiment.

The crystalline carbonate gave the greatest magnesium outgo for both rates. For the other materials at the 8-ton rate the greater losses of magnesium came from the "heavy" forms of oxide and carbonate and the losses from each oxide approximated those from its corresponding carbonate. The magnesium outgo from the 8-ton crystalline carbonate was decidedly greater than that from the 32-ton addition of "light" carbonate during the first year. At the 32-ton rate, the "light" oxide gave an outgo greater than that from the "light" carbonate. The greater solubility of the crystalline carbonate was explained by the assumption of generation of magnesium bicarbonate through the hydrolytic breakdown of the crystalline compound when it is in contact with water at low CO_2 tensions, as represented by the equation: $5\ MgCO_3+2H_2O \longrightarrow 3\ MgCO_3.Mg(OH)_2 + MgH_2(CO_3)_2$.

All magnesic materials depressed the outgo of calcium, the 32-ton additions being approximately twice as effective as those of 8 tons.

The annual and total carbonate-bicarbonate leachings were parallel to the relationships shown for total magnesium.

Small uniform carbonate occurrences from the 8-ton additions are attributed to magnesium carbonate that was thrown down from the

magnesium bicarbonate contained in the free soil-water before drying, the bicarbonate having been derived from the absorption complex.

The carbonate residue from the 32-ton addition of "light" carbonate far exceeded that from either the crystalline carbonate or the "light" oxide. The residual magnesium from the three 32-ton additions was accounted for as follows: That from the oxide was due to a fixation in excess of that from the 8-ton addition and to incomplete carbonation. That from the light carbonate was due to greater fixation and to a persistence of $Mg(OH)_2$ in the original 3 $MgCO_3.Mg(OH)_2$. That from $MgCO_3.3H_2O$ was attributed to a greater fixation and to an hydrolytic breakdown into 3 $MgCO_3.Mg(OH)_2$, or similar forms.

All eight additions caused a material repression in potash outgo, the heavier additions producing the greater repression.

Sulfate outgo was materially and uniformly enhanced by every material at both rates.

Nitrification was accelerated by the 8-ton additions of the oxides and precipitated carbonates, especially during the first year, the two carbonates being the more effective. The crystalline carbonate failed to show any accelerative influence at the 8-ton rate, and at the 32-ton rate it was decidedly repressive. The nitrate leachings from the "light" oxide and "light" carbonate at the 32-ton rate were only about 70% of the outgo from the untreated soil

It is pointed out that the several forms of oxides possess characteristic properties and that their activities in the soil vary, especially when the additions are larger than the amounts that can be absorbed by the soil. The divergent effects upon nitrification, the uniform acceleration of sulfofication, and the consistently repressive action upon the solubility of both calcium and potassium must be considered. Plants grown after magnesic additions reflect the repression phenomena by a smaller assimilation of calcium and potassium.

The findings are considered in their relation to ratio and antagonism studies

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THE ATTERBERG CONSISTENCY CONSTANTS: FACTORS AFFECTING THEIR VALUES AND A NEW CONCEPT OF THEIR SIGNIFICANCE[1]

L. D. BAVER[2]

The Atterberg consistency constants afford a simple means of determining the relative differences in the consistency of various soils. They are being used by many soil survey workers not only as a measure of variations in the consistency of different soils, but also as an expression of the differences occurring in the horizons of any specific soil profile. Since the value of these constants is in part, if not entirely, dependent upon the amount and nature of the colloidal material present, it is evident that they should furnish some index to the physical characteristics of soils. Although values for the Atterberg constants have been obtained for a large number of soils, a satisfactory interpretation of their significance does not exist

It is the purpose of this paper to discuss the different factors that affect the Atterberg consistency constants and to present a new interpretation of their relationship to the dynamic properties of soils involved in tillage and implement design. The Atterberg constants used in this study were (a) the upper plastic limit, (b) the lower plastic limit, and (c) the plasticity number.

FACTORS AFFECTING THE ATTERBERG CONSTANTS

SIZE AND SHAPE OF PARTICLES

The plasticity of a soil is greatly affected by the size and shape of its particles. Sandy soils possess no plasticity because of their large particles. Soils containing a high percentage of the finer particles manifest considerable plasticity Atterberg (3)[3] found that only those minerals whose particles were of colloidal dimensions were plastic. All of these plastic minerals possessed a plate-like structure, the individual particles being disc-shaped. He attributed the high plasticity of the finer soil fractions to the properties of these disc-shaped particles of colloidal size

The colloidal material, at certain moisture contents, can be pictured, perhaps, as acting as a "lubricant" between the coarser particles, allowing them to slide over each other. The plate-like particles are probably oriented in such a way that their flat surfaces are

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[3] Reference by number is to "Literature Cited," p. 948.

in contact. This orientation increases the amount of contact between the colloidal particles. The increased contact, together with an increase in the proportion of water film surface to the particle mass, may be considered as producing the plastic effects. In other words, between certain moisture contents, the surface tension of the water films between the oriented plate-like colloidal particles imparts to the soil its cohesive properties, enabling it to be permanently molded into any desired shape or form. This moisture range corresponds to the range of plasticity of a soil. Orientation of particles and their subsequent sliding over each other takes place when sufficient water has been added to provide a film around each particle. The amount of water necessary to produce these films corresponds to the moisture content of the lower plastic limit. With an excess of water, above that required at the upper plastic limit, the water films become so thick that the cohesion between particles decreases and the soil mass flows.

A possible mechanism of these plastic effects is illustrated in Fig. 1. The colloidal particles in a soil at low moisture contents are probably arranged haphazardly (Fig. 1, a). The particles are covered by an absorbed water film as the percentage of moisture in the system increases. When the moisture content corresponding to that of the lower plastic limit is reached, the particles are oriented when pressure is applied (Fig. 1, b). The surface tension of these absorbed water films holds the adjacent particles together. When the pressure is increased above that of the tension of these films, the particles slide over each other. When the pressure is removed, the particles do not return to their original positions because they are held in place in their new positions by the tension of the moisture films (Fig. 1, c). This conception permits a fairly simple explanation of the phenomenon of plasticity in soils. Further studies are being made to establish the validity of this theory.

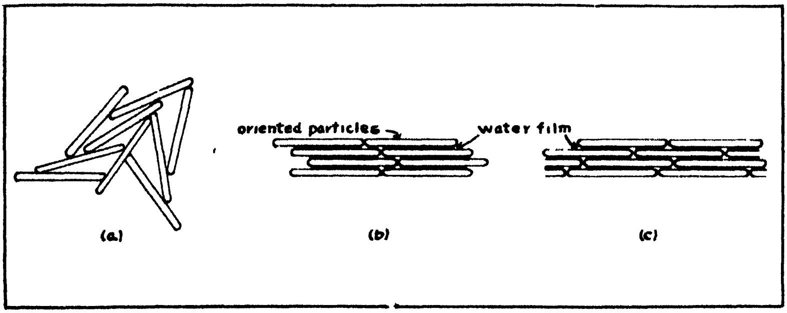

FIG. 1.—Orientation of particles as a cause of soil plasticity.

CLAY AND COLLOID CONTENT

Since plasticity is a function of the finer soil fractions, various soils will possess different plasticities according to the amount of clay or colloids that they contain Atterberg (2) and Terzaghi (10) have shown that an increase in the percentage of clay causes both plastic limits to be higher on the moisture scale and increases the plasticity number. These relationships are shown in Fig 2.

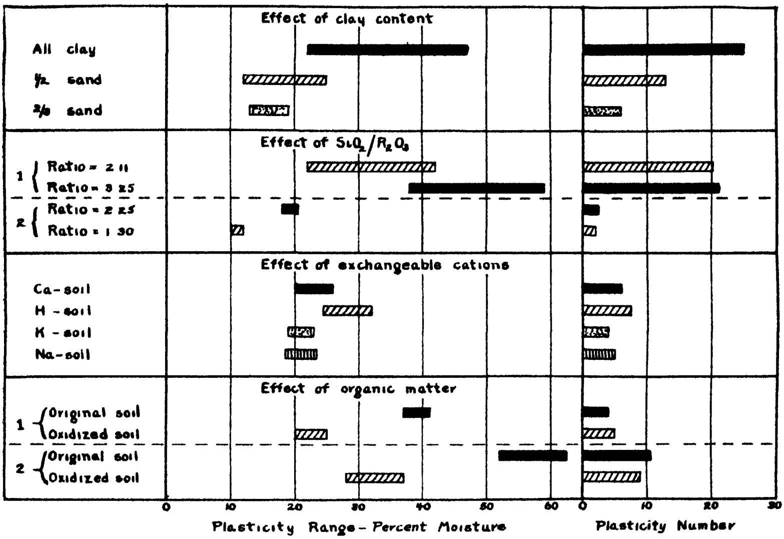

FIG. 2.—The Atterberg consistency constants as affected by various factors.

Russell (9) reports that the plasticity number is a linear function of the clay content The data of Wehr (11) indicate that there is a logarithmic relationship existing between the percentage of clay and the plasticity number Similar relationships have been observed by Atterberg (2) and by the author (5)

TABLE 1.—*Description of soils referred to in this study.*

Soil type	Location	Colloid %	$\frac{SiO_2}{R_2O_3}$	Plastic limits Upper	Plastic limits Lower	Plasticity number
				% moisture		
Lufkin clay	Alabama (Black Belt)	80.0	3.8	64.7	13.2	51.5
Sumter clay . .	Alabama (Black Belt)	—	2.4	33.0	20.1	12.9
Susquehanna clay	Alabama (Coastal Plain)	55.0	2.5	44.2	23.8	20.4
Black clay loam (Aledo)	Illinois	37.0	2.9	32.0	23.8	8.2
Wooster silt loam.	Ohio	25.0	2.2	20.6	18.1	2.5
Cecil clay (pure)	Alabama (Piedmont)	34.0	1.3	17.0	13.0	4.0
Cecil clay (⅓ sand) . . .	Alabama (Piedmont)	23.0	1.3	12.0	10.0	2.0

The data in Table 1 show that the relationship between the plasticity number and the colloid content is not linear. If these results are plotted graphically, the plasticity number appears to be a double logarithmic function of the colloid content. The exact nature of these relationships should be expected to vary with the chemical properties of the colloidal material.

CHEMICAL COMPOSITION OF THE COLLOID

Numerous investigators have shown that the physico-chemical properties of colloidal clay vary with the SiO_2-sesquioxide ratio. Base exchange capacity, swelling, heat of wetting, moisture absorption, and other properties decrease as the ratio of silica to the sesquioxides decreases. The Atterberg consistency constants are similarly affected. The data in Table 1 and Fig. 2 show that the location of the plasticity range on the moisture scale is greatly decreased by a low SiO_2-sesquioxide ratio. The plasticity number does not appear to be materially affected by this ratio. Since moisture absorption and, consequently, the amount of water required to produce a film around the particles, is small in soils having a low ratio, the moisture content at which the soil particles would move over each other would naturally be expected to be low. From a practical standpoint it is probably more important to consider the moisture range over which a soil is plastic than the magnitude of its plasticity number. Two soils may have the same plasticity number but may exhibit plasticity over entirely different moisture ranges.

NATURE OF EXCHANGEABLE CATIONS

It has previously been shown that the nature of the exchangeable cation on the exchange complex has a large influence upon soil plasticity (4). A brief resumé of these data is shown in Fig. 2. The K ion caused a lowering of both plastic limits and a decrease in the plasticity number. The Na ion lowered both plastic limits but increased the plasticity number. The H ion tended to increase the plasticity of those soils which were originally in a state of unsaturation. The Mg and Ca ions increased plasticity, both plastic limits being lowered. These variations perhaps can be explained on the basis of the differences in the hydration of these clays.

There are two types of hydration affecting the plasticity values, namely, water of hydration held between the particles in aggregate formation and the hydration hull or film around the individual particles. In order to produce plastic flow there should be an excess of water present above that required to satisfy the absorptive capacity of the particles or aggregates for water. The K-saturated soils will require less water to produce these plasticity effects than the Na-saturated soils. This is merely a difference in the hydration of the particles as a function of the hydration of ions. The Ca and Mg soils require a certain amount of water to fill the pores in their aggregates; therefore, a larger quantity of water is necessary to produce plasticity than in the case of the K-saturated soils. The high hydration and dispersive action of the Na ion makes the plasticity of the Na-saturated soil greater than those soils saturated with the divalent ions. These results indicate very clearly the differences in plasticity that may be expected as a result of the effect of the exchangeable cation on the soil absorbing complex.

ORGANIC MATTER CONTENT

It has been observed in a study of the plasticity constants of different soil profiles that the upper and lower plastic limits of the surface horizon are always fairly high on the moisture scale when compared with the other horizons of the profile. The presence of organic matter with a relatively high absorptive capacity for water was responsible for these high plastic limits. Fig. 2 shows the effect of oxidizing the organic matter in a soil on the Atterberg constants. This is a review of a previous study (5). It is very evident that organic matter raises both plastic limits on the moisture scale. Removal of organic matter, however, does not affect the plasticity number to any great extent, although there is a tendency towards a decrease in plasticity. Similar effects have been observed by Wehr (11).

A NEW CONCEPT OF THE SIGNIFICANCE OF THE ATTERBERG CONSTANTS

PREVIOUS INTERPRETATIONS OF THEIR SIGNIFICANCE

The original work of Atterberg (1) was apparently conducted with the hope of obtaining some physical criterion for the classification of soils. He made numerous consistency determinations in an attempt to classify the soils of Sweden. Terzaghi (10) has also suggested that the plasticity limits may serve as an index for the physical classification of soils. Soils with a high upper plastic limit should either contain a large quantity of the excessively fine-grained fractions or be rich in scale-like particles. Soils having a high upper plastic limit and a low plasticity number should be in a finely-divided state. If the plasticity number is high, they should contain an abundance of scale-like particles.

Russell (9) has found that the Atterberg constants are a very satisfactory index of soil consistency and of the degree of clay accumulation in the soil profile. So far as soil classification is concerned, these constants will serve as an index of the accumulation of clay within any given soil profile and express the differences in the consistencies of various soils. The question remains, however, whether they can be used to classify different soils in light of the various factors that affect their value.

Terzaghi (10) has related the lower plastic limit to the permeability of clays and to the rate of evaporation of water from soils. He states that the coefficient of permeability of an homogeneous clay decreases rapidly with decreasing water content until, at the lower plastic limit, it becomes practically equal to zero, regardless of the value of the plastic limit. He also states that the rate at which water evaporates from the surface of a clay sample is about 4% greater than the speed with which it evaporates from a free water surface, providing the moisture content is higher than the lower plastic limit. For moisture contents equal to or smaller than the lower limit of plasticity, the physical properties of the soil water are no longer identical with those of free water.

Terzaghi (10) has reported that the compression of a soil increases rapidly with moisture above the moisture content of the lower plastic limit. The compression is small for low moisture contents. The break in the curve showing the relation of the deformation of a clay to the percentage of moisture corresponds approximately to the lower plastic limit. This break is called "the critical bearing point." Therefore, this point can be determined for any soil by using the value for the lower plastic limit.

Wehr (11) has interpreted the lower limit of plasticity as being that wetness above which the soil is in danger of being puddled by cultivation. The plasticity number, if small, is interpreted as denoting the ease of tilth without puddling. If this number is wide there is considerable danger of puddling the soil if it is worked at a wetness above the lower plastic limit. The Atterberg constants are considered as being the best index to "soil tilth." Although these studies of the significance of the Atterberg constants show that there is some relation between these constants and soil tilth, sufficient evidence of the nature of these relationships is not available to warrant more specific conclusions.

RELATION OF THE ATTERBERG CONSTANTS TO THE DYNAMIC PROPERTIES OF SOILS

Since soil consistency is a term used to designate the manifestation of the physical forces of cohesion and adhesion acting within the soil at various moisture contents, a distinct correlation between these constants and the physical forces involved in tillage should be expected.

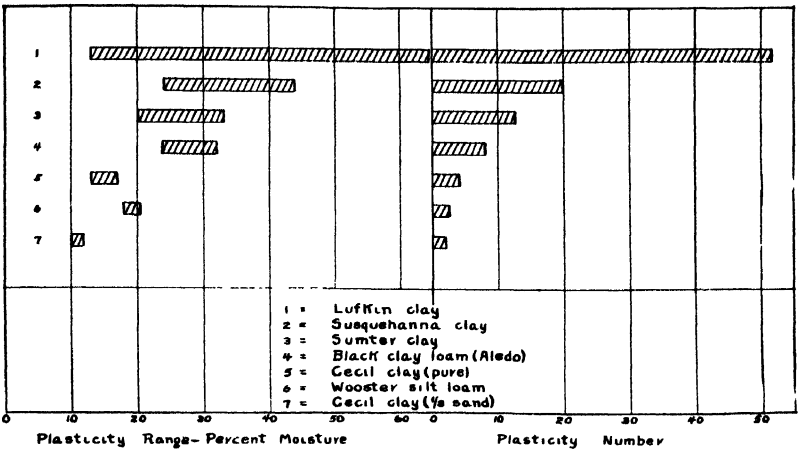

FIG. 3.—The Atterberg consistency constants of the soils referred to in this study.

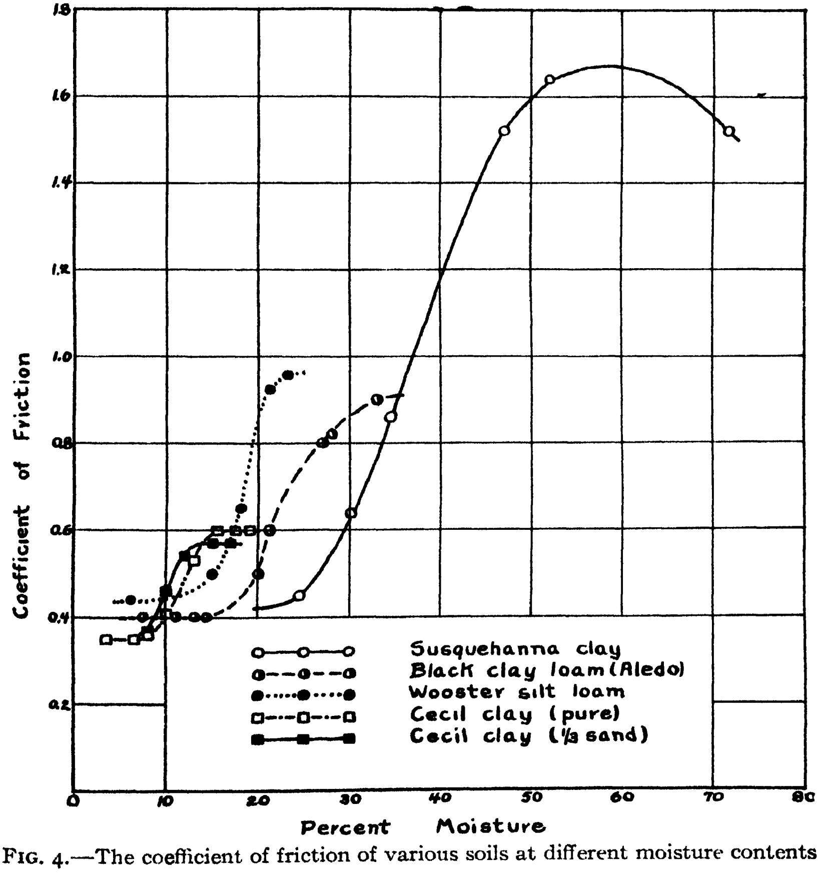

FIG. 4.—The coefficient of friction of various soils at different moisture contents.

Nichols (6) has shown that, among others, the following dynamic properties are involved in tillage problems: Coefficient of internal resistance or shear value of the soil, friction of soil and metal, and the resistance of the soil to compression. The summation of the effects of all these dynamic properties is expressed in the force required to pull any implement, a chisel for example, through the soil. A complete description of the methods used for measuring these properties is given in the recent work of Nichols (6). In order to determine the relationship of the Atterberg constants to the dynamic properties of soils, seven widely different soils were studied. A brief description of these soils is given in Table 1. The values for the Atterberg constants are also shown in Fig. 3.

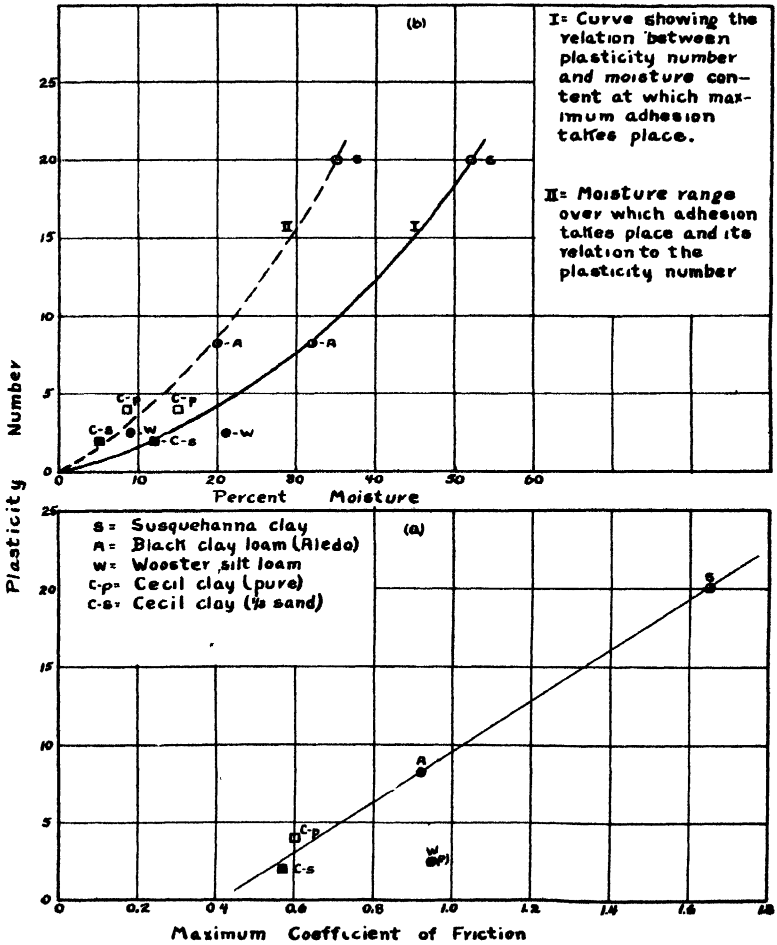

FIG. 5.—The relation of friction to the plasticity number.

FRICTION AND ADHESION

The relationship of the coefficient of friction to the moisture content of soils is given in Fig. 4. The "friction" curves are straight lines up to the moisture content at which adhesion takes place, where the curves rapidly rise to a maximum point from which they gradually decline. The moisture range over which adhesion takes place and the moisture content at which maximum adhesion occurs appear to be definite values for each soil.

Maximum adhesion occurs at a moisture content fairly close to that of the upper plastic limit The data shown in Fig. 5, a indicate that maximum adhesion is proportional to the plasticity number. This should be expected since the plasticity number is a function of the percentage of clay. The curves in Fig 5, b show that there is a relationship between the plasticity number and the moisture range over which adhesion occurs, as well as between the plasticity number and that moisture content at which maximum adhesion takes place. These relationships between adhesion and the Atterberg constants appear to be definite enough to warrant a safe calculation of the friction curve of any soil for any particular metal from the Atterberg constants.

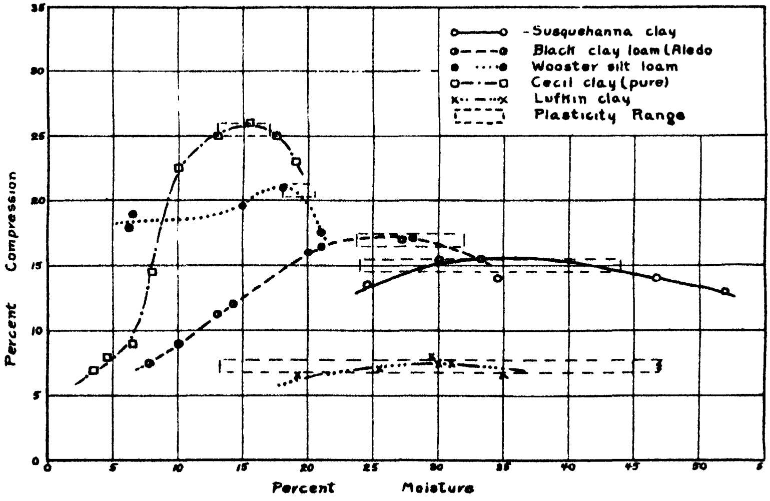

FIG. 6.--The compressibility of various soils at different moisture contents and its relation to the plasticity range

COMPRESSION

The compression values of the soils studied at different moisture contents are shown in Fig. 6. With forces of a magnitude generally used in tillage, all soils have a maximum compressibility at a definite moisture range for each particular soil. This moisture range is approximately the same as that over which plasticity exists. In other words, soils reach their maximum state of compressibility throughout the plastic range. Therefore, the Atterberg constants afford a means of calculating the range of compressibility of soils.

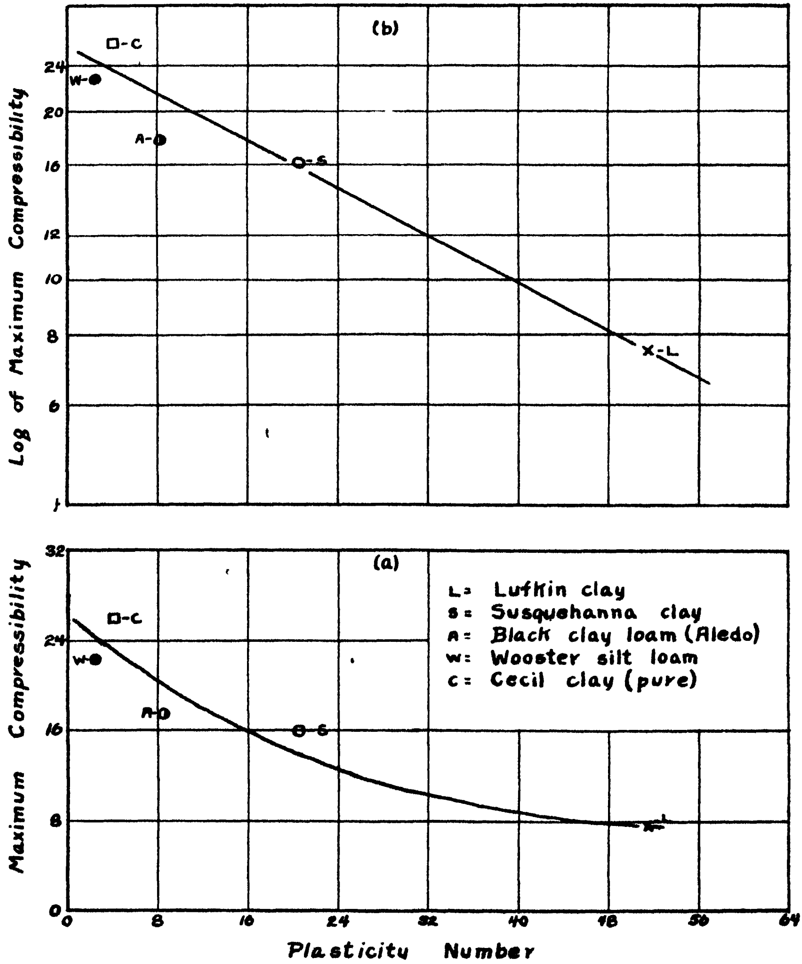

FIG. 7.—The relation of maximum compressibility to the plasticity number.

The data shown in Fig. 7 indicate that the maximum compressibility of a soil is a logarithmic function of the plasticity number. These two relationships permit the calculation of the range of maximum compressibility of a soil and the magnitude of this compression from the Atterberg constants.

CHISEL STUDIES

The curves in Fig. 8 show the resistance offered by each of three soils to the passage of chisels. Two 1-inch chisels set at angles of 45° and 90° to the surface of the soil were used. The resistance curves are S-shaped. The relationships of the Atterberg constants to the resistance offered by soils are shown in Fig. 9, a and Fig. 9, b. The curves in Fig. 9, a show that the maximum pounds pull is a logarithmic function of the plasticity number. A double logarithmic relationship exists between the plasticity number and that moisture content at which the resistance to pull begins to increase rapidly, that is, the first break in the resistance curves. This is shown in Fig. 9, b.

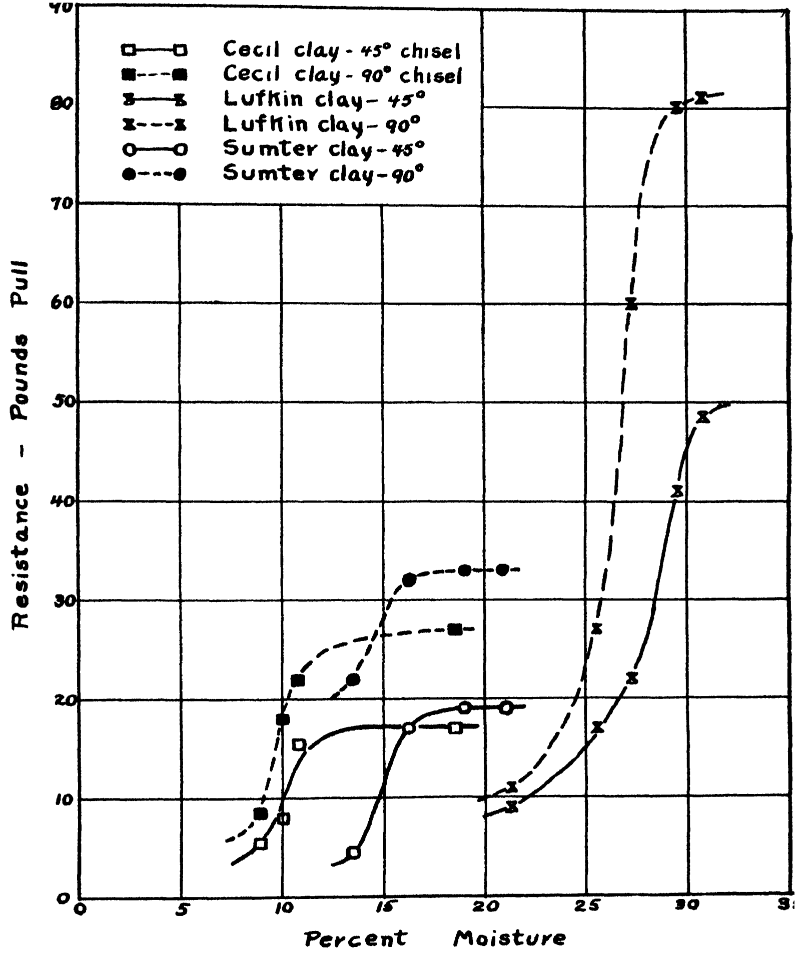

FIG. 8.—The resistance to pull of various soils at different moisture contents.

These data show that the resistance offered by soils to the passage of tillage implements can be predicted from a knowledge of the Atterberg constants. A more detailed discussion of these relationships as they apply to tillage and to implement design is given in other publications (7, 8).

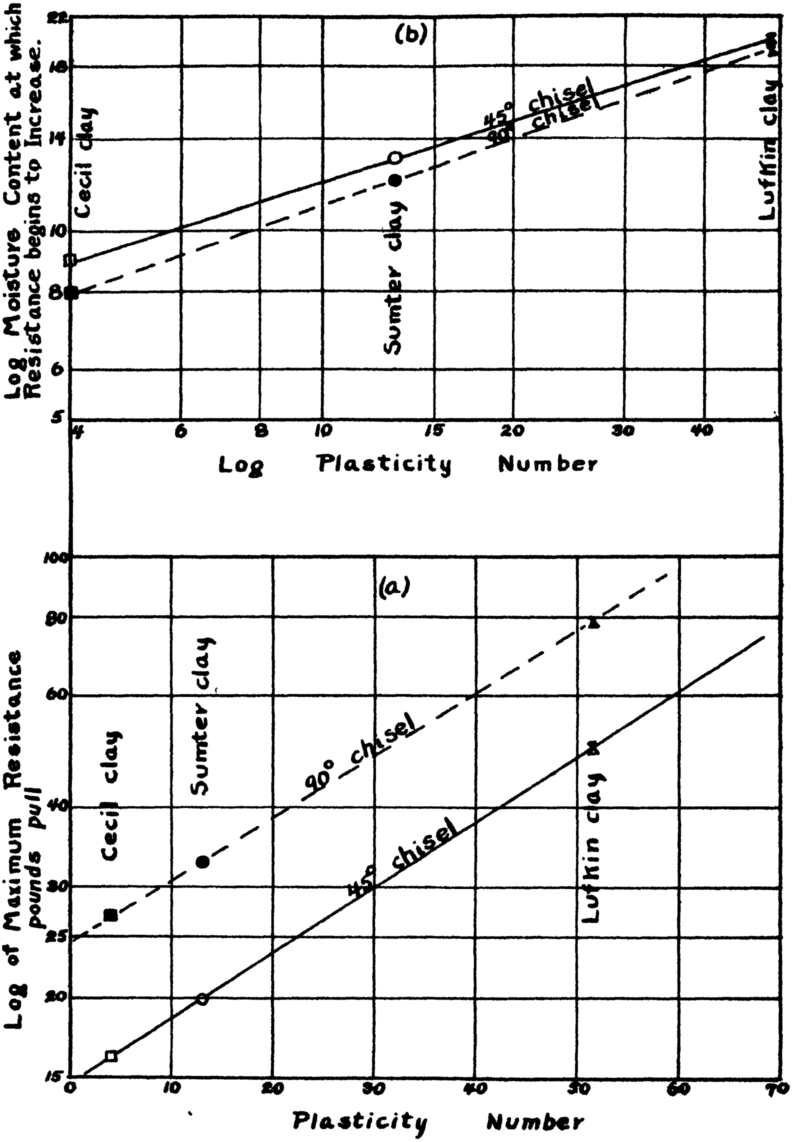

FIG. 9.— The relation of the resistance to pull of soils to their plasticity numbers.

DISCUSSION

Results similar to those above have been obtained in preliminary investigations of the cohesion and shear values of these soils. Further studies are being made of these relationships with the hope of obtaining accurate mathematical formulations whereby the dynamic properties of soils can be calculated from data of the Atterberg constants.

Since these properties are evidently closely associated with the Atterberg consistency constants, the factors discussed in the first part of the paper will also affect the dynamic properties of soils. These relationships indicate that the Atterberg constants of any soil may be interpreted in terms of the physical forces involved in tillage problems, thereby adding considerable value to the determination of soil consistency by means of these constants.

SUMMARY

The Atterberg consistency constants are affected by the following factors:

1. *Size and shape of particles.*— Disc-shaped, colloidal particles impart plasticity to soils. Plasticity increases with the content of these fine particles. A new theory is advanced to explain the plasticity of soils on the basis of the orientation of the plate-like, colloidal particles.

2. *Clay and colloid content.*—Soils containing a high percentage of clay or colloids possess high plasticities.

3. *Chemical composition of the colloid.*—A low SiO_2-sesquioxide ratio of the colloidal material extracted from soils is associated with a low plasticity range on the moisture scale.

4. *Nature of exchangeable cations.*—The divalent cations tend to increase the plasticity of soils by raising both plastic limits. The K ion decreases plasticity and lowers both plastic limits. The Na ion lowers both plastic limits but increases plasticity.

5. *Organic matter content.*—Organic matter causes plasticity to occur at high moisture contents but does not materially affect the magnitude of the plasticity.

The following relationships exist between the Atterberg constants and the dynamic properties of soils:

1. Maximum adhesion occurs at a moisture content fairly close to that of the upper plastic limit.

2. Maximum adhesion is proportional to the plasticity number.

3. The moisture range over which adhesion takes place and the moisture content at which maximum adhesion occurs appear to be functions of the plasticity number.

4. The range of maximum compressibility is approximately the same as the plasticity range on the moisture scale.

5. Maximum compressibility is a logarithmic function of the plasticity number.

6. The maximum resistance offered by a soil to the passage of chisels is a logarithmic function of the plasticity number.

7. A double logarithmic relationship exists between the plasticity number and that moisture content at which the resistance of a soil to the passage of chisels begins to increase rapidly.

From these results and preliminary work with cohesion and shear, it appears possible to predict, by means of the Atterberg consistency constants, the values of the dynamic properties of any plastic soil.

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A COMPARATIVE STUDY OF STUDENT'S METHOD AND BESSEL'S FORMULA[1]

JOHN P. CONRAD[2]

In a recent paper (1)[3] reporting the data secured from applying ammonium sulfate to barley and wheat following sorghum, odds were calculated by two methods. These are summarized as follows:

> "In all of these figures the differences in odds as derived from Bessel's formula and from Student's method are somewhat different than has generally been reported. There is an impression derived from the literature, though not actually stated in so many words, that Student's method should give better odds in most cases than Bessel's formula method. In these tests the writer believes that the arrangement of plats should make either method applicable. If anything, Bessel's formula is in most cases theoretically at a disadvantage, but of the 54 different pairs of odds calculated by the two methods Bessel's formula gives the better odds (sometimes by far) in 44 cases"

Though other cases have been reported by Love (7 p 222), Kemp (6), and Hayes (4), the stress in the literature has seemed to be in the opposite direction This has resulted in a feeling, at least among some experimenters, that one is always on the safe side if Bessel's formula is used. The data referred to above do not bear this out. It seems desirable to find out as many factors as are operative in causing different odds to be secured and to evaluate the effect of each. The study has brought out other possibilities and methods which are also included

In a comparison of odds for the same data secured on the one hand by Bessel's formula from the table of Pearl and Miner (12) and on the other hand from Student's tables (18), there are three factors which cause different odds, *viz*, the method of computing odds; the handling of correlation, and the difference in the functions, especially for small numbers

METHOD OF COMPUTING ODDS

Statisticians are undoubtedly well aware that the odds in the tables of Pearl and Miner (12) are derived from a different basis than those of Student (18) Many experimenters, among whom was the writer (1), do not realize this. The difference can be shown by the following example.

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[1] Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication June 2, 1930.

[2] Assistant Agronomist.

[3] Reference by number is to "Literature Cited," p. 961.

In considering the odds of the difference of two means, let $M_{A\text{-}B} = 6 \pm 6$. This means that the odds are equal that the true value of $M_{A\text{-}B}$ lies between 0 and + 12. The odds are equal that the true value lies outside of the range 0 to + 12. But the odds are 3:1 that the true value of difference is greater than 0; or the odds are 3:1 that the difference $M_{A\text{-}B}$ is significant.

Again, let $M_{A\text{-}B} = 6 \pm 2$. This means that the chances are even that the true value of $M_{A\text{-}B}$ lies between + 4 and + 8. The odds are 22.26:1, i e., when $M_{A\text{-}B} = 3\ E_{A\text{-}B}$, that the true value lies between 0 and + 12. These are the odds given in the table of Pearl and Miner (12) The chance of the true value being greater than 0 is obviously not 22.26:1, but slightly more than twice, or 45.5:1. This is the point of view in Student's tables (18), the title for which is "Tables for estimating the probability that the mean of a unique sample of observations lies between $-\infty$ and any given distance of the mean of the population from which the sample is drawn" Speaking in terms of the probability curve, Pearl and Miner have secured their odds by dividing the middle area by the area of both ends, while Student has secured his by dividing the middle area plus one end by the area of the other end.

In some comparisons of these two methods the odds for Bessel's formula have been taken from the table of Pearl and Miner or tables which yield similar odds, while those for Student's method have been obtained from his tables. Thus, Love (7, p. 222), using a method which eliminates correlation, i.e., equation VI below, gets odds of "about 40:1 that B is better than A," while with Student's method for the same data "the odds are 25.5:1 that the mean difference (7.1 bushels) is significant." For a fair comparison the same method of deriving the odds should be used. Either of the following two methods could be used, but the same method should obviously be used in the same comparison.

Method of securing odds	Comparative odds in Love's hypothetical case	
	Bessel's formula with correlation eliminated	Student's method
Middle area divided by area of both ends,	about 40:1	12.3:1
Middle area plus one end area divided by other end area	about 80:1	25.5:1

In some of the comparisons of odds between these two methods, then, to Bessel's formula have been attributed but slightly less than one-half of the odds which it should have in comparison with odds from Student's method.

CORRELATION

As the handling of correlation necessitates the use of algebra, for the sake of clearness, the following symbols and formulae are given with the citations for the latter. Where necessary, the symbols are changed from the original to conform to those used in this paper.

n_A = number of values of the variable A
$A_1, A_2,—A_n$ = different values of the variable A
M_A = mean of A = $\frac{A_1 + A_2 + \text{————————} A_n}{n}$
$M\text{-}_{AB}$ = difference of means = $M_A—M_B$
= mean of paired differences = $\frac{(A_1—B_1) + (A_2—B_2)\text{————}(A_n—B_n)}{n}$
D_A = deviation of each A from M_A
D_{A-B} = deviation of each (A—B) from M_{A-B}
σ_A = standard deviation of A = $\sqrt{\frac{\Sigma D^2_A}{n}}$
σ_{A-B} = standard deviation of (A—B) = $\sqrt{\frac{\Sigma D^2_{A-B}}{n}}$
E_A = the probable error of A = $\frac{\pm 0.6745\sigma_A}{\sqrt{n-1}}$

By Bessel's formula according to Mellor (11), Kelley (5), and others, $E_{A\ B} = \sqrt{E_A^2 + E_B^2}$ (I)

But this does not take into consideration the possibility of correlation between the yields of A and B Kelley (5), Student (19), and others (3, 6, 14) give the following equation to show the true relationship involved.

$$\sigma_{A\ B}^2 = \sigma_A^2 + \sigma_B^2 — 2\, r_{AB}\, \sigma_A\, \sigma_B \qquad \text{(II)}$$

where r_{AB} = the coefficient of correlation between A and B.

Stadler (17) refers to r as the coefficient of heterogeneity where used in connection with field trials.

Where $n_A = n_B$ from equation II, we may secure

$$E_{A-B}^2 = E_A^2 + E_B^2 — 2\, r_{A-B}\, E_A\, E_B \qquad \text{(III)}$$

Where $r_{AB} = 0$, equation III becomes equation I and equation II becomes

$$\sigma_{A-B}^2 = \sigma_A^2 + \sigma_B^2 \qquad \text{(IV)}$$

As the various values given in equation II are easily obtained, except r_{AB}, its value will be obtained without making the usual correlation table from a modification of that equation, namely,

$$r_{AB} = \frac{\sigma_A^2 + \sigma_B^2 — \sigma_{A-B}^2}{2\, \sigma_A\, \sigma_B} \qquad \text{(V)}$$

Love (7) has suggested a probable error as follows:

$$E_{A\text{-}B} = \frac{\pm\ 0.6745\ \sigma_{A\text{-}B}}{\sqrt{n-1}} \qquad \text{(VI)}$$

When the probable error of the mean of two sets of observations is to be secured, undoubtedly pairing is to be preferred. In comparing more than two sets of observations the number of combinations taken two at a time rapidly increases according to the relations $\frac{n\ (n-1)}{2 \cdot 1}$. Hence, with a table of yields of six varieties or six soil treatments, the pairing would necessitate 15 combinations, a long and tedious procedure. Many data are presented in tabular form, each mean being accompanied by its probable error. Obviously, the easiest way to make comparisons rapidly would be by the use of equation I, assuming $r_{AB} = 0$.

It is interesting to find out how great an error may result from this procedure, assuming that equation III is the more accurate. Taking equation I as the method of calculation and equation III as the true value, the ratio $\frac{\text{equation III}}{\text{equation I}}$ gives the factor of error, F, in using equation I.

$$F = \sqrt{\frac{E_A^2 + E_B^2 - 2E_A\ E_B\ r_{AB}}{E_A^2 + E_B^2}}.$$ The variation in r_{AB} may be from -1 to $+1$.

In Table 1 is shown a hypothetical case in which equation I gives the same value as does equation III because the data are so chosen as to make r_{AB} equal to 0 In this case, F = 1 so the results by either equation are the same

TABLE 1.—*Hypothetical case illustrating the computation of the probable error of the difference, $M_{A\text{-}B}$, by equations I and III where the coefficient of correlation between A and B is 0.*

	A			B			Paired differences A—B		
Series	Yield	D	D²	Yield	D	D²	Yield	D	D²
1	20	—2	4	16	—2	4	4	0	0
2	24	+2	4	20	+2	4	4	0	0
3	20	—2	4	20	+2	4	0	—4	16
4	24	+2	4	16	—2	4	8	+4	16
Mean	22			18			4		
	σ		2			2			$2\sqrt{2}$
	E		$\frac{0.6745\ (2)}{\sqrt{3}}$			$\frac{0.6745\ (2)}{\sqrt{3}}$			$\frac{0.6745\ (2\sqrt{2})}{\sqrt{3}}$

$$\sqrt{E_A^2 + E_B^2} = \frac{0.6745\ (2\sqrt{2})}{\sqrt{3}} \qquad E_{A\text{-}B} = \frac{0.6745}{\sqrt{3}}\ (2\sqrt{2})$$

By equation V, $r_{AB} = \frac{4+4-4 \cdot 2}{2 \cdot 2 \cdot 2} = 0.$

But in actual field trials only infrequently will r_{AB} approach 0. With E_A and E_B constant, F will obviously have a maximum value when r = —1, for $r = -1$, $F = \frac{E_A + E_B}{\sqrt{E_A^2 + E_B^2}}$.

It can be shown by the differential calculus that F has its maximum value when $E_A = E_B$. The maximum value for F is $\sqrt{2}$. The more accurate probable error, i e., from equation VI, cannot be more than the $\sqrt{2}$ times the value obtained with the use of equation I. In this connection Stadler (17) has brought up the possibility from a different point of view but states "In actual practice no negative heterogeneity coefficients have been reported." The coefficients reported by him were for replication of a relatively large number of plats and ranged from 0 138 to 0.830. When the number of plats is small there is more liklihood of securing a negative value Thus, with four replications and the use of equation V, in 1 instance out of 18, a negative value for r_{AB} was secured, namely, —0 34. The positive values ranged from 0.09 to 0 99 for the other 17. Undoubtedly, many instances of data behaving as the last two in Table 1 have been observed, but in a large number of replications averaged together their effect toward securing a negative value for r would be offset by the effect of others in a positive direction. In Table 2 is given a hypothetical case where r_{AB} is equal to 1

TABLE 2.—*Hypothetical case illustrating the computation of the probable error of the difference, M_{A-B} by equations I and III where the coefficient of correlation between A and B is —1.*

	A			B			Paired differences A—B		
Series	Yield	D	D²	Yield	D	D²	Yield	D	D²
1	20	—2	4	20	+2	4	0	—4	16
2	24	+2	4	16	—2	4	8	+4	16
3	20	—2	4	20	+2	4	0	—4	16
4	24	+2	4	16	—2	4	8	+4	16
Mean	22			18			4		
σ		2			2			4	
E		$\frac{0.6745\,(2)}{\sqrt{3}}$			$\frac{0.6745\,(2)}{\sqrt{3}}$			$\frac{0.6745\,(4)}{\sqrt{3}}$	

$$\text{By equation V } r_{AB} = \frac{4+4-16}{2 \cdot 2 \cdot 2} = -1.$$

Though negative correlation in field trials may occur occasionally, positive correlation is undoubtedly more often encountered. Considering the possibility of the ratio, F, when r_{AB} attains its maximum value, + 1, we have $F = \frac{E_A - E_B}{\sqrt{E_A^2 + E_B^2}}$. By observation it may be readily seen that here F has its lowest numerical value, o, when $E_A = E_B$. A hypothetical case illustrating the computations when $r = +1$ is given in Table 3.

TABLE 3.—*Hypothetical case illustrating the computation of the probable error of the difference, M_{A-B}, by equations I and III where the coefficient of correlation between A and B is + 1.*

	A			B			Paired differences A—B		
Series	Yield	D	D²	Yield	D	D²	Yield	D	D
1	20	—2	4	16	—2	4	4	0	0
2	24	+2	4	20	+2	4	4	0	0
3	20	—2	4	16	—2	4	4	0	0
4	24	+2	4	20	+2	4	4	0	0
Mean	22			18			4		
σ			2		2			0*	
E			$\frac{0.6745\ (2)}{3}$		$\frac{0.6745\ (2)}{3}$			0*	

By equation V $r = \frac{4+4-0}{8} = 1$.

*Probably only theoretically, even with these figures, would $E_{A-B} = 0$. For that to be true, it would be necessary for the measurements to be exactly the same down to an infinitesimal amount. In practice, even though the figures as far as weighed would come out with 0 variation, still more accurate weighing would bring out differences that would make the error appreciable though small. In weighing the dry matter from triplicate pots, equal figures have occasionally been obtained for the yields from each of three pots. In that case a value for the error somewhat lower than half of the least count in weighing was taken for σ and the corresponding E computed. This possibility should undoubtedly be borne in mind in interpreting data reported by Love and Brunson (10) and by Salmon (15) in their hypothetical cases.

It will be noticed that E_A and E_B are respectively the same in Tables 1, 2, and 3 because of the way the data are chosen. E_{A-B}, however varies markedly. From the data and algebraic manipulations it can be seen that the more accurate value for E_{A-B}, i.e., from equation VI, varies between o and $\sqrt{2}$ times that secured by taking equation I as the method of computation, i.e., assuming $r_{AB} = 0$.

DIFFERENCE IN THE FUNCTIONS, ESPECIALLY FOR SMALL NUMBERS

Before computing the odds from the tables, such as that of Pearl and Miner (12), the ratio of the mean to its probable error is secured, $\frac{M_{A-B}}{E_{A-B}}$. From equation VI this becomes $\frac{M_{A-B}}{E_{A-B}} = \frac{M_{A-B}\sqrt{n-1}}{\sigma_{A\cdot B}\ \ 0.6745}$

Then, $\frac{0.6745\ \ M_{A-B}}{E_{A-B}} = \frac{M_{A-B}\ \ \sqrt{n-1}}{\sigma_{A-B}} = x.$

Values of x are used in the original tables of Sheppard (16), hence this may be written $x_{A-B} = \frac{M_{A-B}\ \sqrt{n-1}}{\sigma_{A-B}}$ (VII)

Let P equal the probability of an observation or the mean of a set of observations falling outside the range of $-x$ to $+x$ Fisher (2) gives the values of x corresponding to definite values of P. Kelley (5) gives values of x corresponding to definite values of "I" which equals ½ (1—P) and "p" which equals 1—½ P. Sheppard (16) gives values of "½ (1 + a)" which equals 1 —½P for definite values of x. The tables of x cited above presuppose a large sample from an infinite population Because the use of these formulae with small numbers gives values too high, Love (9) has suggested the use of the "corrective terms" by Pearson (13, p. 529). If such corrective terms are represented by K', then equation VII becomes

$$y_{A\text{-}B} = \frac{M_{A\text{-}B} . K' . \sqrt{n-1}}{\sigma_{A\text{-}B}} \qquad \text{(VIII)}$$

Because values of P secured from equation VII are too low for small samples, Student has worked out his method, which is represented as follows: $z_{A\text{-}B} = \frac{M_{A\text{-}B}}{\sigma_{A\text{-}B}}$ (IX)

Tables for the probability which equals (1 —½ P) are given by Student (18) and the corresponding odds by Love (8)

A large number of sets of data might be accumulated, and the probability or odds worked out by the two different methods could be compared over as wide a range as would be available. In this way an empirical relation could undoubtedly be secured that would prove interesting. Fortunately, however, this is not necessary because with a few algebraic manipulations a simple relationship between the two is secured.

Combining equations VII and IX, we secure

$$x_{A\text{-}B} = \frac{M_{A\text{-}B}}{\sigma_{A\text{-}B}} . \sqrt{n-1} = z_{A\text{-}B}\sqrt{n-1} \qquad \text{(X)}$$

But the tables will not give equal odds from the same data because the tables in x are designed for large numbers and the z tables for small. Fisher (2) uses t in place of x for small numbers. Then for small numbers equation VII becomes

$$t_{A\text{-}B} = \frac{M_{A\text{-}B} \sqrt{n-1}}{\sigma_{A\text{-}B}} = z_{A\text{-}B} \sqrt{n-1} \qquad \text{(XI)}$$

Values of t are given in Fisher's Table 4, p. 139, for values of n from 2 to 31 and for definite levels of significance expressed in terms of P. In using his tables it should be remembered that his "n" equals $n-1$ in this paper, i.e., Fisher uses "n" as the "number of degrees of freedom" which in this case is one less than when n equals the number of values of a variate. Fisher's Tables 4 and 1 show definitely that as n becomes infinite $t = x$.

If equation VIII is changed to $\frac{y_{A-B}}{K} = \frac{M_{A-B}\sqrt{n-1}}{\sigma_{A-B}}$, the right hand parts of equations VII, VIII, and XI are equal. By assuming varying values for $\frac{M_{A-B}\sqrt{n-1}}{\sigma_{A-B}}$ a direct comparison of odds may be made, values of x being secured from Sheppard's tables, values for y

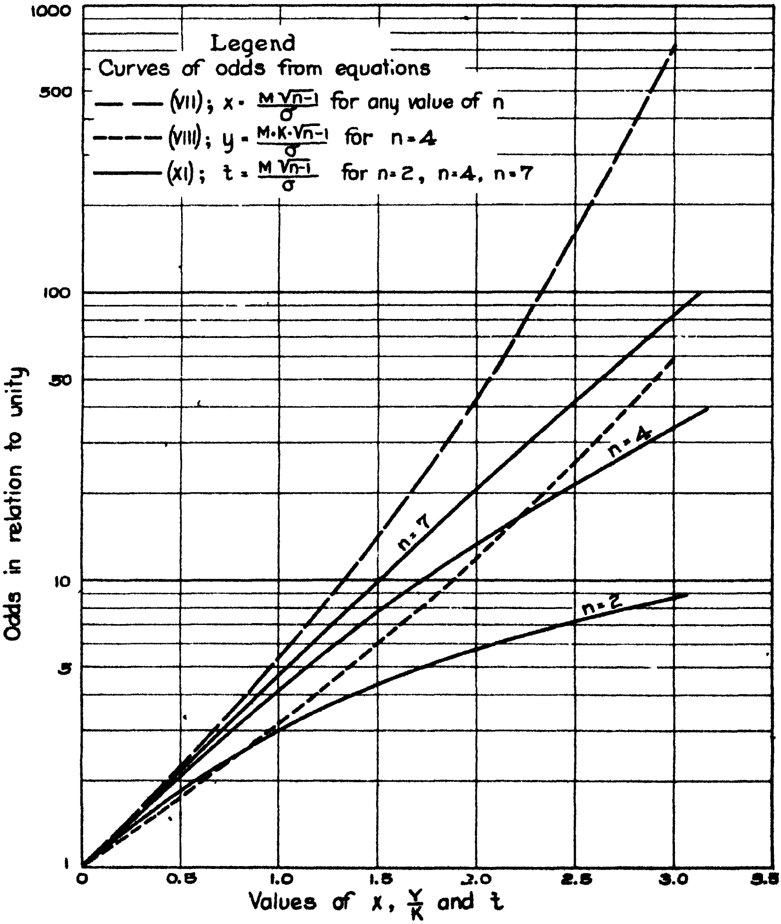

FIG. 1.—Comparison of odds from equations VII, VIII, and XI. Any given set of data will give the same values for x, y/K, and t, hence comparisons of the curves should be made on a vertical line determined by the data.

being secured as if they were for x in Sheppard's tables, and values for t being secured from Fisher's Table 4, but by computing odds as for x and y. Statisticians give different odds as the border line of significance, Fisher (2) gives as the border line of significance a probability where P = 0.05 or odds of 19.1 This is on the basis of computing odds by dividing the area of the middle section by the area of both ends.

In the case of the odds for $M_{A\text{-}B}$, generally in field tests what is desired is the odds that it is greater than 0 Odds of 19:1 that the difference $M_{A\text{-}B}$ is greater than 0 in Fisher's tables will then be found under P = 0 1; odds of 39 1, under P = 0 05; and odds of 99:1, under P = 0.02 Fig. 1 gives a comparison of odds that would be secured from equations VII, VIII, and XI over a wide range of data The odds in relation to unity are given as ordinates on a logarithmic scale, while various values of x, y/K, and t (all equal for a given set of data) are given as abscissas Comparisons of odds for any given set of data should be made on a vertical line, the position of which is determined by the data concerned

The curve of odds for Love's modification of Bessel's formula, equation VII, is given in the long dashes In solid lines are given the curves of odds by Student's method for $n = 2$, $n = 4$, and $n = 7$ For equation VIII, i e, using Pearson's corrections, is shown the curve of corresponding odds for $n = 4$ This figure indicates that equation VII, i e., Bessel's formula corrected for correlation, will always give higher odds than Student's method for the same data.

TABLE 4.—*A comparison of odds between equation XI (Student's method) and equation VIII.*

$n =$ $K^* =$	4 0.7071	7 0.8452	15 0.9309	30 0.9661	∝ 1.0000	Levels of significance Student's odds† (XI)
t‡	1.638	1.440	1.345	1.311	1.282	
y§ (VIII)	1.158	1.217	1.252	1.267	1.282	
Odds‖ (VIII)	*7.1*	*7.95*	*8.5*	*8.75*	*9.0*	*9 : 1*
t‡	2.353	1.943	1.761	1.699	1.645	
y§ (VIII)	1.664	1.642	1.639	1.641	1.645	
Odds‖ (VIII)	*19.8*	*18.9*	*18 7*	*18.8*	*19.0*	*19 : 1*
t	3.182	2.447	2.145	2.045	1.960	
y (VIII)	2.250	2.068	1.997	1.976	1.960	
Odds (VIII)	*80.8*	*50.7*	*42.5*	*40.5*	*39.0*	*39 : 1*
t	4.541	3.143	2.624	2.462	2.326	
y (VIII)	3.211	2.657	2.443	2.378	2.326	
Odds (VIII)	*1,510*	*252*	*136*	*114*	*99*	*90 : 1*

*From Pearson (13, p. 529).

†As defined in this paper.

‡As defined by Fisher (2).

§$y = t\ K$.

‖Odds in relation to unity.

The relation between odds secured by means of Pearson's corrective terms and Student's method are interesting. For $n = 4$ the curves cross at about odds of 17:1. By combining equations VIII and XI, we can get $y = t\ K'$. But since different tables have been used, different numerical results are obtained. Using the corrective terms K' on the values of t selected from Fisher's table will give us an idea for what range of significance this relationship holds approximately true. This is shown in Table 4.

The agreement may be considered to be good for odds of 19:1, while Pearson's corrective terms will give lower odds than Student's method below this level of significance and higher odds above it. The agreement in odds between equations VIII and XI is good in the range covering what might be called the border line of significance.

Where correlation is corrected for or eliminated by pairing, three formulae have been suggested as a basis for computing odds. They are equations VII, VIII, and XI. Where correlation is disregarded or not available, other formulae may be used. The one corresponding to VII is

$$x_{\text{A-B}} = \frac{\text{M}_{\text{A-B}} \sqrt{n-1}}{\sqrt{\sigma_{\text{A}}^2 + \sigma_{\text{B}}^2}} \qquad \text{(XII)}$$

This is Bessel's formula.
With Pearson's corrective terms this becomes

$$y'_{\text{A-B}} = \frac{\text{M}_{\text{A-B}} K' \sqrt{n-1}}{\sqrt{\sigma_{\text{A}}^2 + \sigma_{\text{B}}^2}} \qquad \text{(XIII)}$$

Fisher (2, p. 107) gives a method by which it is possible "to extend Student's treatment of the error of a mean to the comparison of the means of two samples," i.e., t is sought when σ_{A}, σ_{B}, and n are known but r_{AB} unknown. If $n_{\text{A}} = n_{\text{B}}$, i.e., if the two samples to be compared have the same number in each, his value for t may be reduced to the following equation

$$\frac{\text{M}_{\text{A-B}} \sqrt{n-1}}{\sqrt{\sigma_{\text{A}}^2 + \sigma_{\text{B}}'}} \qquad \text{(XIV)}$$

When $\sqrt{\sigma_{\text{A}}^2 + \sigma_{\text{B}}^2}$ instead of $\sigma_{\text{A-B}}$ is given or can be computed, odds may be secured with the use of equations XII, XIII, and XIV. Fig. 1 may be used for comparing the odds thus calculated for $n = 4$. Comparison of the odds secured by different equations for any given set of data is made on a vertical line. With equation XIV which is obtained by a change of notation and of algebraic reduction from Fisher's formula (2, p.107), odds are secured when $n = 4$ from the graph for $n = 7$. This unusual procedure happens as follows:

Instead of looking up t in the table under "n" equal to n—1 as for equation XI Fisher uses a value of "n" equal to $2n$—2. Applying this to the case in Table 1, we have with equation XIV

$$(a)\ t_{A\text{-}B} = \frac{4\sqrt{3}}{2\sqrt{2}} = 2.45,\ \text{"n"} = 6,$$

while with equation XI

$$(b)\ t_{A\text{-}B} = \frac{4\sqrt{3}}{2\sqrt{2}} = 2.45,\ \text{"n"} = 3.$$

Fisher's tables are not extensive enough to show this comparison. Hence, a change to z is desirable in order to employ Student's tables.

$$\frac{t}{\sqrt{n-1}} = z \text{ where Fisher's "n"} = n-1 \text{ of Student's.}$$

(a) $z = 1.000$ $n = 7$, Odds = 39.2:1

(b) $z = 1.412$ $n = 4$, Odds = 20.7:1

This is especially surprising as $r_{AB} = 0$, and by the relations shown in equation II it would be expected that the odds would be equal.

In order to compare the results secured by the six formulae each is tried on the data included in Tables 1, 2, and 3 with the odds so computed given in Table 5. Since equations VIII and XI were

TABLE 5.—*A comparison of odds for the significance of the difference of the means* $M_{A\text{-}B}$ *secured by each of the six methods of computing when applied to data given in Tables 1, 2, and 3.*

			Odds	
		Table 1	Table 2	Table 3
	$r_{AB} =$	0	—1	+1
(VII)	$x_{A\text{-}B} = \frac{M_{A\text{-}B}\sqrt{n-1}}{\sigma_{A\text{-}B}}$	139	23	∞*
(XII)†	$x_{A\text{-}B} = \frac{M_{A\text{-}B}\sqrt{n-1}}{\sqrt{\sigma_A^2 + \sigma_B^2}}$	139	139	139
(VIII)	$y_{A\text{-}B} = \frac{M_{A\text{-}B}\,K\sqrt{n-1}}{\sigma_{A\text{-}B}}$	23	8.1	∞*
(XIII)	$y_{A\text{-}B} = \frac{M_{A\text{-}B}\,K\sqrt{n-1}}{\sqrt{\sigma_A^2\ \sigma_B^2}}$	23	23	23
(XI)‡	$t_{A\text{-}B} = \frac{M_{A\text{-}B}\sqrt{n-1}}{\sigma_{A\text{-}B}}$	20.7	10.0	∞*
(XIV)	$t_{A\text{-}B} = \frac{M_{A\text{-}B}\sqrt{n-1}}{\sqrt{\sigma^2_A + \sigma^2_B}}$	39.2	39.2	39.2

*See foot note to Table 3.
†Bessel's formula.
‡Student's method.

designed to use with small numbers, it would seem wise then to use them whenever possible. The decision as to which of the two should be used is left to the statistician.

From Fig. 1 and Tables 4 and 5, the close agreement in odds secured from equations VIII and XI covering the range that is considered the border line of significance is apparent. Equations XIII and XIV, as they do not take correlation into consideration, cannot give as valuable results as equations VIII and XI. Equation VII gives higher odds than Student's method; equation XI where n is not large. When correlation is positive, as it generally is, equation VII likewise gives higher odds than Bessel's formula, equation XII. The assurance in using Bessel's formula lies in the expectancy that correlation will be high enough to offset the higher odds secured in practice by equation VII. When correlation approaches 0 or is negative, the use of Bessel's formula, equation XII, would lead to very high odds as compared to those from Student's method, equation XI, or equation VIII when used on the same data.

For any given case it would be possible to work out just what coefficient of correlation would be necessary to have in the data concerned in order to secure with Bessel's formula odds equal to those secured from the same data by Student's method. With the use of equation VIII, which gives odds, at the border line of significance at least, closely approximating those from Student's method (equation XI), a more general relationship can be worked out.

To solve for r_{AB} with equations VIII and XII, let $y_{A-B} = x_{A-B}$ or

$$\frac{M_{A-B} . K \sqrt{n-1}}{\sigma_{A-B}} = \frac{M_{A-B}\sqrt{n-1}}{\sqrt{\sigma_A^2 + \sigma_B^2}}.$$

Then $\sigma_{A-B} = K\sqrt{\sigma_A^2 + \sigma_B^2}$

By equation II

$$\sigma_A^2 + \sigma_B^2 - 2\, r_{AB}\, \sigma_A\, \sigma_B = K^2\,(\sigma_A^2 + \sigma_B^2)$$

and

$$r_{AB} = \frac{(1 - K^2)\,(\sigma_A^2 + \sigma_B^2)}{2\, \sigma_A\, \sigma_B}.$$

This is a general relationship the numerical value of which depends upon the ratio of σ_A to σ_B and the value of K which is different for different values of n. Thus, in cases where $\sigma_A = \sigma_B$, $r_{AB} = 1 - K^2$. For $n = 4$, $K = 0.7071$ and $r = (1-K^2) = 0.50$.

From inspection it can be readily seen that for any other value of $\frac{\sigma_A}{\sigma_B}$ than unity, r_{AB} will have a greater value than $(1-K^2)$. This can be proved by the methods of the differential calculus. In this case, then, in order to be assured that Bessel's formula will not give too high odds, where $n = 4$, the coefficient of correlation in the data must be at least 0.50. For higher values of n this necessity is decreased until for $n = \propto$ the necessity occurs that the coefficient of correlation at least should not be less than 0.

SUMMARY

The difference in odds secured from the same data by the two methods is shown to be due to three factors as follows:

1. *Method of computing odds.*—In type examples followed by many agriculturists, to Bessel's formula is attributed slightly less than one-half of the odds to which it is entitled in a comparison with odds from Student's tables.

2. *Handling of correlation.*—Formulae and hypothetical cases are given illustrating the effect of eliminating correlation, i.e., by pairing (Student's method) as against disregarding it (Bessel's formula).

3. *Differences in the functions, especially for small numbers.*—Different formulae where correlation is eliminated by pairing are compared, algebraically, graphically, and by means of tables, as to the odds secured by their use. Bessel's formula with correlation eliminated by pairing, equation VII, is shown to give higher odds than does either the same formula corrected for small numbers, equation VIII, or Student's method, equation XI. The agreement between odds secured from equation VIII and from Student's method is shown to be very close at odds of 19:1.

It is shown that unless the coefficient of correlation r_{AB} is appreciable in the data concerned, Bessel's formula with small numbers gives higher odds than equation VIII, and consequently higher than Student's method.

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HEIGHT OF STUBBLE AND STRAW YIELDS OF SMALL GRAINS[1]

J. W. Taylor and J. H. Martin[2]

A taller stubble usually is left when small grains are harvested with a combine than when harvested with a binder. A lodged crop, however, must be cut close to the ground, causing a large bulk of straw to pass through the machine. Consequently, in lodged grain the threshing capacity of the combine is much reduced and the threshing losses are increased owing to overloading of the straw rack and chaffer. The harvesting difficulties accompanying lower cutting with a combine seem to increase at an even greater rate than the increasing length of the cut stems. If many green weeds are encountered in low cutting, combine harvesting becomes very difficult.

In harvesting experimental plats of small grains where straw yields are taken, an attempt usually is made to cut the crop at a uniform height above the soil, but a plat often is cut high if stones, corn stubble, or numerous weeds are encountered, and is cut low if the crop is lodged. The height of stubble left often varies with the height of the crop.

The data here reported were obtained chiefly to determine the relative quantities of straw which must be handled by a combine when different heights of stubble are left at harvest, but the results also have a bearing upon the straw yields obtained from experimental plats.

EXPERIMENTAL METHODS

The experiments were conducted at the Indiana Agricultural Experiment Station, Lafayette, Ind., in 1927, and at the U. S. Department of Agriculture, Arlington Experiment Farm, Rosslyn, Va., in 1928.

Bundles of grain were harvested by hand and taken to a shed where the culms were cut off at definite intervals and the grain and straw (including chaff) in each section were weighed. The plants were all harvested at the soil surface except the wheat at Lafayette, Ind., which was cut about 6 inches above the ground. The heads were evened up on some of the material at Lafayette before the bundles were cut into sections, but at Arlington Farm all bundles were cut from the base upward just as the plants stood in the field. A few short tillers containing grain, especially in Fulghum oats at Arlington Farm, introduced slight irregularities in the data. The crop of all other samples would be regarded as being fairly uniform in height.

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RESULTS

LAFAYETTE, IND., 1927

The weights of straw obtained from Purkof wheat and Silvermine oats cut at various heights at Lafayette, Ind., in 1927, are shown in Table 1. Both crops were fairly uniform and in good condition, the wheat yielding about 25 bushels and the oats 40 bushels per acre. The heads were cut off with a short portion of the peduncle attached as in close harvesting with a combine. In all three tests approximately three-fourths of the combined weight of straw and chaff was found below the level of the lowest heads. The proportion of the straw in the 6-inch sections decreased upward owing to the decrease in the thickness of the culms of the plants and fewer nodes.

The total and grain weights of the heads as cut from the stems were determined. The Purkof wheat with a portion of the peduncle attached had a "shelling" percentage of about 62% and the Silvermine oats of 64%. Complete removal of the peduncle of the oats increased the "shelling" percentage to 70. Heads of Purplestraw wheat, with all of the peduncle removed, grown in a plat yielding about 40 bushels per acre at Arlington Farm in 1929 showed a "shelling" percentage of 81.

ARLINGTON FARM (VIRGINIA) 1928

The data at Arlington Farm were taken on two varieties of wheat and one variety each of barley, oats, and rye. The weights from each 2-inch section of the bundles beginning at the ground level were recorded, but the weights were later combined into 4-inch sections in order to eliminate irregularities in the data caused chiefly by the presence of numerous nodes in certain of the sections. The percentages of straw and grain in the crops cut at different heights at Arlington Farm are shown graphically in Fig. 1.

The curves in Fig. 1 are of similar form for all grains, but with different slopes due to differences in height and uniformity of height of the plants. The curves of straw weights were all of approximately logarithmic form, while the grain curves were sigmoid (S-shaped). Comparisons of the straw and grain curves of each variety show that a considerable proportion of the straw stands below the level of the lowest heads containing grain and that 60 to 80% of the straw is

TABLE 1.—*Weights of straw cut at different heights at Lafayette, Ind., in 1927.*

Purkof wheat*

Height cut in inches	Cumulative weights† Total in grams	Cumulative weights† %
6	25	16.2
12	45	29.2
18	65	42.2
24	82	53.2
30	99	64.3
36	107	69.5
42	115	74.7
Heads	154	100.0

Silvermine oats

Tops even

Height cut in inches	Cumulative weights Total in grams	Cumulative weights %
2.5	12	7.6
8.5	34	21.5
14.5	58	36.7
20.5	80	50.6
26.5	101	63.9
32.5	121	76.6
Heads (10 inches)	158	100.0

Butts even

Height cut in inches	Cumulative weights Total in grams	Cumulative weights %
6	37	20.6
12	75	41.7
18	108	60.0
24	134	74.4
Heads (18 inches)	180	100.0

*Tops even.

†Not including 6-inch stubble which was left.

below the level of all except the few small heads on late tillers.

All of the grain would have been harvested if the rye had been cut with a combine at a height of 40 inches above the soil surface. At this height 76% of the straw would be left as stubble. If the rye had been badly lodged, necessitating cutting 4 inches above the ground, only 10% of the straw would have been left standing, and a combine would have had to handle more than three and one-half times as much straw. Similar, though less striking, results were obtained for the other grains. These data show why low cutting with a combine overloads the machine and necessitates slower cutting to prevent serious threshing losses.

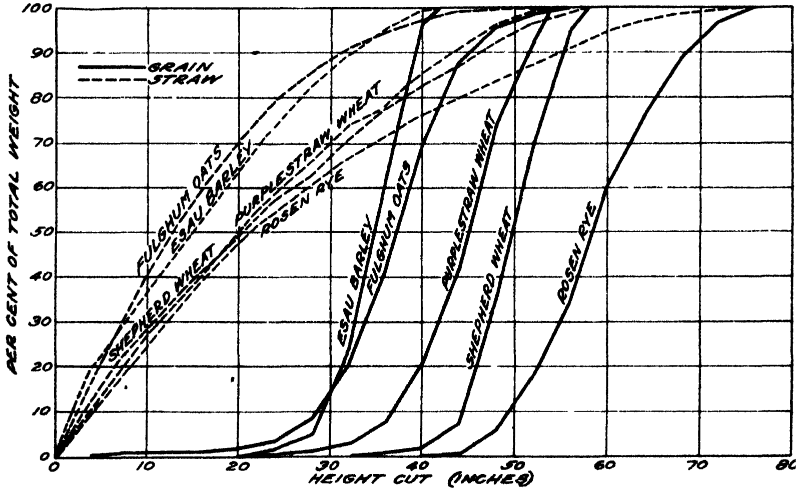

FIG. 1.—Percentages of the total weight of straw and grain obtained when barley, oats, rye, and wheat were cut at various heights above the ground.

The rate of upward decrease in the thickness of stems is indicated in part by the slope of the straw weight curves. This may also be demonstrated by calculations of the percentage of the total height below which 50% of the straw was found. These percentages were as follows: Barley, 36; oats, 23; rye, 29; Purplestraw wheat, 37; and Shepherd wheat, 34. A part of the decreased straw weight probably is due to short culms. The solid node of a culm is much heavier than the same length of hollow internode, and since the nodes are closer together at the lower end of the culm, this also is a factor in the heavier straw weights near the ground.

The ratios of straw to grain in the experiments at Arlington Farm are shown graphically in Fig. 2.

There was a rapid decrease in the ratios as cutting was higher. Fulghum oats had a straw to grain ration of 1.72:1 at the ground level, 1.44:1 at a height of 4 inches, and 0.92:1 at a height of 12 inches. The ratio was more than 50% higher at 4 inches than at 12 inches. These variations in height of stubble frequently occur in harvesting a series of experimental plats. It is evident that only limited importance can be attached to straw yields unless the height of cutting is uniform.

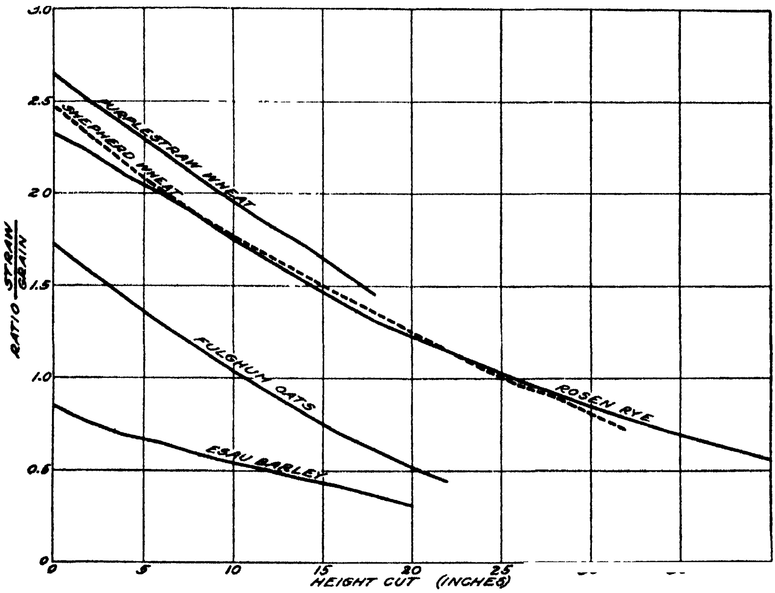

FIG. 2.—Ratios of $\frac{\text{straw}}{\text{grain}}$ in two varieties of wheat and one variety each of barley, oats, and rye.

SUMMARY

In a fairly uniform field of grain approximately 60 to 80% of the straw and chaff is found below the level of the lowest heads.

Straw weights decrease rapidly with higher cutting, largely because the culms decrease in thickness upward from the base to the peduncle.

Three and a half times as much straw sometimes is harvested in cutting a lodged crop a with combine as in harvesting an erect crop.

Straw yield data from experimental plats are of limited value unless the height of cutting is uniform.

A COMPARISON OF SOME EFFECTS OF BLAST FURNACE SLAG AND OF LIMESTONE ON AN ACID SOIL[1]

F. H. CRANE[2]

A number of investigators, including Barnette (2,3,4,)[3], Connor (5), Cowles (6), Hartwell and Pember (7), MacIntire and Willis (8), Scheidt (9), and Schollenberger (10), have reported work with certain silicates, mainly di-calcium silicate, as substitutes for lime in correcting soil acidity or soil toxicity arising therefrom. Their work indicates that di-calcium silicate compares very favorably with other liming materials, especially if applied in chemically equivalent amounts (usually calculated from the calcium and magnesium content). On some soils the di-calcium silicate appears to be more effective than equivalent amounts of limestone.

In 1916, Ames (1) reported trials with blast furnace slag and precipitated $CaCO_3$. The slag was not so effective as the $CaCO_3$. More recently, extensive tests with blast furnace slag have been carried on at the Pennsylvania (12, 13) and Ohio (14) agricultural experiment stations. The tests at Pennsylvania indicate that on the basis of calcium and magnesium applied, 20-mesh blast furnace slag is somewhat better than 20-mesh limestone, although less effective when compared on the ton basis. The slag apparently had an effect in increasing yields beyond that which its content of calcium and magnesium would lead one to suspect. Granulated slag was considerably less effective than 20-mesh slag or limestone. The Ohio trials also showed the granulated slag to be much less effective than ground limestone.

The results reported in this paper are from pot cultures carried on in 1925–26. The soil used is classified by the Illinois Soil Survey as Gray Silt Loam On Orange Mottled Tight Clay. One-gallon pots were filled with 5 kilograms of air-dry soil with which the treatment materials had previously been mixed. The rates of application are based on 2 million pounds of water-free soil.

The limestone had a neutralizing value of 94.4% $CaCO_3$ equivalent (official A.O.A.C. method). The official A.O.A.C. method involves solution of the material in an excess of standard acid, the excess of acid then being titrated with standard alkali, using phenolphthalein as the indicator. The limestone contained 36.6% of calcium and

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[1] Contribution from the Division of Soil Fertility, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication June 9, 1930.

[2] Associate in Soil Fertility.

[3] Reference by number is to "Literature Cited," p. 972.

0.7% of magnesium. The slag was obtained from Youngstown, Ohio. Its neutralizing value by the above method was 65%. It contained 30.6% calcium, 1.4% magnesium, and 16.0% silicon. A later sample from the same source contained 32.3 % calcium, 1.4% magnesium, 1.9% iron, 3.9% aluminum, 17.4% silicon, 1.7% sulfur, and 0.5% of carbonate carbon. The 100-mesh slag was prepared by grinding granulated slag. Although the larger particles may be rather easily crushed in the fingers, the slag is rather resistant to grinding to 100-mesh size. The screen test of the granulated slag follows:

Coarser than 4-mesh	0.5%
4 to 10-mesh	11.1%
10 to 20-mesh	29.6%
20 to 40-mesh	34.8%
40 to 60-mesh	13.0%
60 to 80-mesh	2.8%
80 to 100-mesh	1.4%
Through 100-mesh	6.6%
	99.8%

Red clover was planted between 5 and 6 months after the treatments were added, the soil having been kept moist in the meantime. The clover was harvested at the end of seven months' growth. Determinations of pH were made on the moist soil, using the quinhydrone electrode, 15 months after the treatments had been applied. The soil from each set of duplicate pots was composited for determina-

TABLE 1.—*Effect of blast furnace slag and of limestone on the clover yield, exchangeable calcium, and reaction of an acid soil.*

Pot No.	Treatment	Clover yield (water-free) in grams	pH	Exchangeable calcium*	Hopkins acidity*	Jones acidity*
1	None	0.58	4.85	830	1,690	3,190
2	None	0.15	4.75	—	—	—
3	Limestone, 1 ton 100-mesh	3.21	5.53	1,260	350	2,060
4		3.47	5.66	—	—	—
5	Slag, 1 ton 100-mesh	1.83	5.36	1,120	500	2,190
6		2.72	5.44	—	—	—
7	Limestone, 2 tons 100-mesh	4.65	6.16	1,730	80	1,400
8		3.54	6.16	—	—	—
9	Slag, 2 tons 100-mesh	3.00	5.90	1,430	150	1,470
10		3.17	5.90	—	—	—
11	Limestone, 4 tons 100-mesh	7.01	7.44	3,100	10	540
12		5.71	7.43	—	—	—
13	Slag, 4 tons 100-mesh	6.20	6.49	2,550	10	990
14		4.50	6.28	—	—	—
15	Slag, 4 tons granulated	1.88	5.54	1.650	310	2,150
16		2.00	5.30	—	—	—
Maximum variation in duplicate determinations			0.11	126	25	250

*Pounds per 2,000,000 pounds soil.

tions of exchangeable calcium, Hopkins acidity, and Jones acidity. The treatments applied, crop yields, and results of the acidity and exchangeable calcium determinations are shown in Table 1.

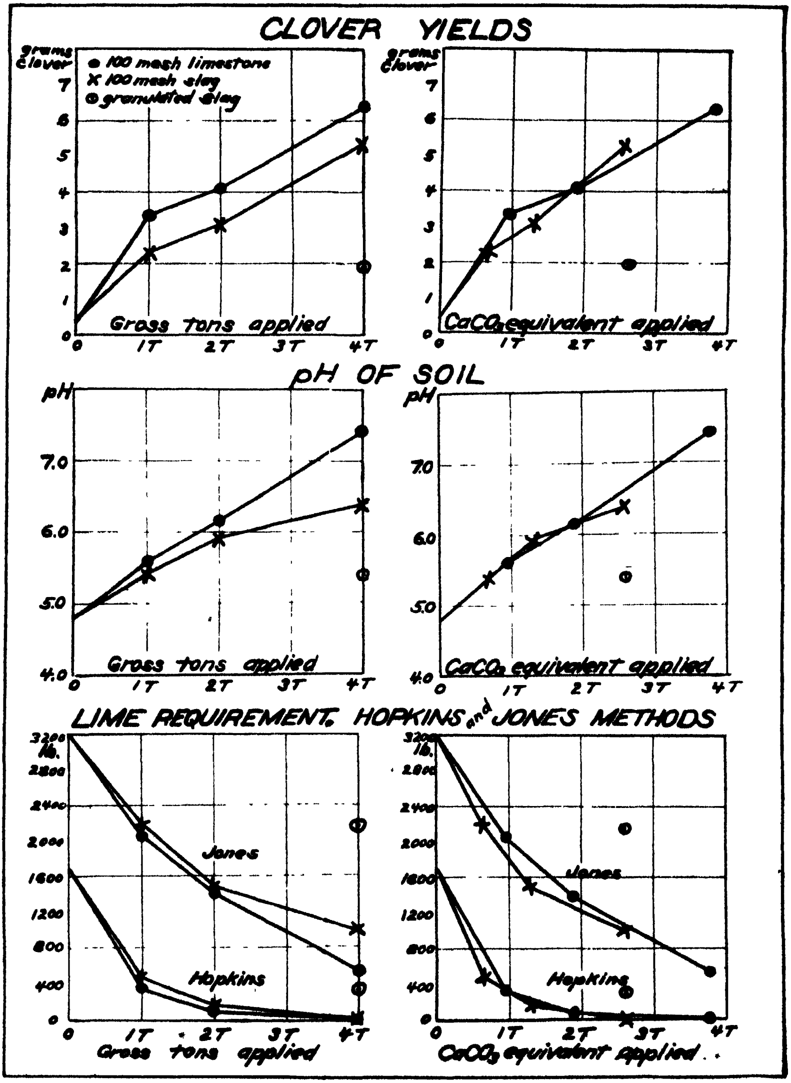

FIG. 1.—Comparison of some effects of blast furnace slag and of limestone on the basis of gross tons applied to the soil and the CaCO$_3$ equivalent applied.

The usual arbitrary factors were not used in computing the results of the Hopkins and Jones determinations. For the determination of exchangeable calcium, 25-gram samples of soil were leached with 1 liter of normal KCl. All of the limestone had apparently reacted with the soil, since carbonate determinations on the samples indicated that the soil treated with limestone contained no more carbonate than the untreated soil, the amount in any case being very little greater than the error in analysis.

When compared on the gross ton basis, limestone was somewhat superior to the slag in every respect. If, however, these materials are compared on the basis of $CaCO_3$ equivalent as determined by titration to an endpoint with phenolphthalein, the results agree very closely, as shown by the curves in Fig. 1. According to the Jones determination, the slag was somewhat superior to the limestone when compared on the titration basis. The neutralizing values of the limestone and slag determined on this same basis were 94.4% and 65%, $CaCO_3$ equivalents, respectively. Slag has been evaluated usually on the basis of its total calcium and magnesium. The $CaCO_3$ equivalents of the limestone and slag, computed from their content of calcium and magnesium, are 94.5% and 82.5%, respectively. A considerable discrepancy is evident in the case of the slag between the $CaCO_3$ equivalents as determined by the two methods. Under the conditions of this experiment, the comparative effects of the limestone and slag correlated more closely with the relative neutralizing values as determined by titration to an endpoint with phenolphthlein than with the $CaCO_3$ equivalents computed from the calcium and magnesium contents. The value obtained for the slag by titration agrees very well with the 61% effectiveness of ground slag as compared with ground limestone obtained at the Ohio Station (14) in plat trials. They found a relative value for slag of only 43% in cylinder experiments.

Owing to a considerable buffer action in the case of the slag, titration with methyl orange as the indicator gives a $CaCO_3$ equivalent considerably higher than that determined with phenolphthalein, although less than the values calculated from the total calcium and magnesium contents. A portion of this extra neutralizing, value shown by the methyl orange titration over the phenolphthalein titration may be attributed to the presence of the weakly basic elements, iron and aluminum, which would be little if at all effective in changing the reaction of an acid soil. These bases are not included in neutralizing value as measured by the phenolphthalein titration. Part of the calcium and magnesium may exist in the slag as the aluminum silicates of calcium and magnesium and these forms are probably of little value in correcting soil acidity.

The recovery as exchangeable calcium, of the calcium added, was somewhat lower from the slag than from the limestone. A higher percentage recovery of the calcium added was secured with the larger applications. The recovery from the 1-, 2,-, and 4-ton applications of the 100-mesh limestone was 59, 61, and 77%, respectively, of the calcium added, while from the corresponding applications of 100-mesh slag, the recovery was 46, 53, and 70%, respectively. From the granulated slag applied at the 4-ton rate, the recovery was 33%.

In crop yield, pH, Jones acidity, and Hopkins acidity, the application of 4 tons of the granulated slag gave results approximately equal to those from 1 ton of 100-mesh slag. This 25% effectiveness of the granulated slag as compared with 100-mesh slag suggests that the effect of this material over the period of time of the experiment may have been due mainly to the finer than 40-mesh material, since 23.8% passed a 40-mesh sieve. The increase in exchangeable calcium in the soil, however, from the 4 tons of granulated slag was greater than from 2 tons of 100-mesh slag in contrast with its 25% effectiveness in other respects.

SUMMARY

Blast furnace slag and limestone were compared in greenhouse and laboratory tests. On the gross ton basis 100-mesh limestone was somewhat superior to 100-mesh slag in its effects on red clover growth and soil reaction with the soil used, but on the basis of $CaCO_3$ equivalent, as *determined by titration using phenolphthalein as indicator*, the two materials had nearly the same effectiveness. The $CaCO_3$ equivalent of these materials, as computed from their contents of total calcium and magnesium, was a less satisfactory measure of their relative effectiveness, as shown by clover yields and effects on soil reaction, than was the $CaCO_3$ equivalent obtained by titration. Four-ton applications of granulated slag gave results approximately equal to those from 1 ton of 100-mesh slag. .

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BOOK REVIEWS

(HANDBUCH DER BODENLEHRE) HANDBOOK OF SOIL SCIENCE

III. THE MAJOR SOIL GROUPS AND THEIR DISTRIBUTION OVER THE EARTH

E. Blanck, Editor. Berlin: J. Springer. VIII + 550 pages, illus. 1930. $13.50 unbound; $14.25 bound.

The editor is to be congratulated for the courage of publishing this volume on soil morphology. In these days of controversy about soil classification it is indeed a risk trying to bring the multitude and diversities of facts and opinions on soil profile studies under one cover. The editor has succeeded remarkably in offering a clear and easily readable treatise of the complex subject. The entire presentation is based on the climatic principle of soil classification, not because the editor considers it the best one, but because it has been worked out over larger areas and in more detail than any other scheme so far proposed. Soils that do not fit into the climatic system (so-called acclimatic and endodynamomorphic soils) are to be treated in the next volume.

The book opens with a historical review on the development of climatic soil classification (by E. Blanck) in which particular credit is given to the pioneer work of Dokutschajeff, Hilgard, and Richthofen. *The soils of the cold regions*, being of little agricultural value but attracting much interest from the standpoint of soil formation, are divided into "arctic soils" (by W. Meinardus) and "mountain soils" (by H. Jenny).

The section on *the soils of the temperate region, including subtropics*, contains descriptions of eight climatic soil types, namely, "podsolic soils" and "brown timber soils" (by H. Stremme), "yellow earth and yellow loams" (by H. Harrassowitz), "Terra Rosa" (by E. Blanck), "tschernosems" and "prairie soils" (by H. Stremme), "chestnut soils" and "alkali soils" (by A. A. J. v. Sigmond). The two latter chapters are an outstanding and critical representation of alkali soil research both in Europe and in the United States.

The section on the *soils of the subtropical-tropical transition zone* consists of discussions on "subtropical black earth" (by F. Giesecke) and "crust soils" (by E. Blanck). Seventy-four pages are devoted to Harrassowitz's authoritative treatise on *tropical soils* which contains many new facts and viewpoints. Contrary to common belief, typical laterite is not an extensive soil type, and strange enough, it occurs, according to Vageler, in semihumid and slightly arid regions, rather than in highly humid tropics where podsols are to be found. A chapter on true *desert soils* (by H. Mortensen and G. Linck) and a summary on "degraded soils" (by H. Stremme) complete this large volume.

Since Glinka's famous book (1914), no general treatise on climatic soil types has appeared that could compare with the present thorough and up-to-date monograph. Numerous analyses, diagrams, and excellent photographs help to make this volume an outstanding event in the present literature on soil science. (H. J.)

PLANT BIOLOGY

By H. Godwin. New York: Macmillan. IX + 265pages, illus. 1930. $2.90.

This text book, although written primarily for first year medical students at Cambridge University, might well be read with profit by other students of biology. The author has managed to combine in a comparatively small treatise discussion of all the essential and fundamental processes of living plants which a student of biology wishes to know. The scholarly style and logical arrangement of the text give the book a quality that most readers will appreciate.

Throughout the book more emphasis is laid on the physiology of plants than on their morphology. Yet discussions of essential structures are far from omitted. To the root, stem, and leaf of higher plants three separate chapters are devoted.

After introducing the subject by a chapter on "The Living Plant", the author develops his thesis by discussing in some detail the biochemistry involved in plant processes. From this is the natural step to plant metabolism. A separate chapter is devoted to photosynthesis. Several chapters are devoted to the study of bacteria, yeasts, and the algae. In this way the student is brought into contact with these important lower organisms, as well as the fundamental physiological processes they are made to illustrate.

The text is well and adequately illustrated by diagrams and sketches. The latter include many enlarged and simplified drawings of plant structures, and all have very complete keys.

In spite of the tremendous breadth of field of plant biology today, Godwin has brought to the student a modern conception of the subject, and this he has managed to do without making his story appear too sketchy. The essentials are not only there, but in sufficient detail, and given in such a way that one is not conscious of a too elementary approach. One leaves the book with the feeling that within its class it is a finished product. (L. R. H.)

AGRONOMIC AFFAIRS

SUMMER MEETING OF SOUTHERN AGRONOMISTS

The fourth annual summer meeting of southern agronomists was held in South Carolina, August 19, 20, and 21. The meeting consisted mostly of an extensive tour of the state when several of the branch experiment stations were visited. The morning of August 19 was devoted largely to an inspection of the College and agronomy farms at Clemson College. Various phases of research work with cotton and fertilizers were studied. A comprehensive analysis and rate of application test of fertilizers to cotton located in Laurens County was visited during the afternoon.

The morning of August 20 was spent in an inspection of a number of experiments with pasture and forage crop plants and summer legumes at the Sandhill Experiment Station near Columbia. Soil and fertilizer investigations with cotton, corn, and soybeans at this station were also of special interest to the visiting agronomists. A visit was made during the afternoon to Hartsville, the home of the Coker Pedigreed Seed Company, where the extensive cotton breeding work of this Company was inspected.

The party visited the Pee Dee Experiment Station at Florence on August 21 and studied the various phases of research work with cotton being conducted there. An examination of the Keitt fertilizer and rotation experiment, one of the oldest and most extensive fertilizer studies in the South, was of especial interest to the visitors.

MEETING OF PURNELL CORN IMPROVEMENT COMMITTEE

The Purnell Corn Improvement Committee held a field meeting at Purdue University, LaFayette, Indiana, Friday, September 26, 1930. The purpose of this meeting was to inspect the corn breeding work under investigation at Purdue University in cooperation with the U. S. Department of Agriculture.

The attendance numbered about 60. There were representatives from Ohio, Indiana, Illinois, Iowa, Nebraska, South Dakota, Minnesota, Kansas, Missouri, Wisconsin, and the U. S. Department of Agriculture.

At the business meeting held in the evening, the following were elected to serve on the executive committee for 1931: Dr. Merle T. Jenkins, Ames, Iowa, *Chairman;* Dr. L. J. Stadler, Columbia, Missouri; and Dr. A. N. Hume, Brookings, South Dakota.

MEETING OF NEW ENGLAND SECTION

The annual meeting of the New England Section of the Society is to be held at the Bellvue Hotel in Boston, November 28 and 29. Sessions are planned on fertilizer ratios; on experimental work with fertilizers for potatoes and allied crops; and on golf turf culture with particular emphasis on diseases, varieties, seed production, and fertilizers. At the banquet on the evening of the 28th, Dr. A. B. Beaumont will discuss present-day conditions in Russia.

NEWS ITEMS

At the request of the Secretary of Agriculture of Mexico, and with the assistance of the Director of the National School of Agriculture at Chapingo, Director Fabian Garcia of New Mexico, Dean H. W. Mumford of Illinois, and Professor John W. Gilmore of California made, during the past summer, an inspection of the agencies for agricultural advancement in Mexico. The visitors were received most cordially and were afforded every opportunity to see the agriculture in the Federal District and in the States surrounding it. They were tendered a banquet by the Agricultural Society of Mexico at which they were presented with the Society's Honorary Diploma.

F. N. BRIGGS, formerly with the Office of Cereal Investigations, U. S. Dept. of Agriculture, has been appointed Assistant Professor of Agronomy and Agronomist in the Experiment Station at Davis, California. He will continue with his investigations on cereal smuts.

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THE AGRONOMIC SIGNIFICANCE OF BASE EXCHANGE[1]

W. P. KELLEY[2]

There are two reasons why I have decided to discuss base exchange at this time. First, the general agronomists, especially those not primarily engaged in the technical study of soils seem to find some difficulty in grasping the essential features of this subject. Various members of this Society have appealed to me at one time or another for reference to a reliable general discussion on base exchange. As many of you are aware, the literature on this subject is quite extensive; it is scattered through a large number of publications in various languages much of which is distinctly technical and difficult to read. Consequently, it is not always the simplest matter to gain a clear idea as to the essential features of base exchange. The second reason is that the importance of base exchange is not infrequently over-magnified, and sometimes considerably exaggerated, by students of base exchange.

Every one admits that soil is a complex material. Even the simplest soil is composed of a large number of individual components and of course most soils are highly complex. Now, not all of the soil constituents take part in base exchange. Many, if indeed not all, of the constituents of a given soil contribute to its properties, however, at least to some extent. There seems to be some tendency among soil workers to explain too much by base exchange. It is hardly necessary for me to state that I consider base exchange to be one of the important principles of soils. Nevertheless, nothing is gained by exaggerating its importance. In fact the very opposite is true, for to explain any phenomenon on a false basis is in reality to retard the orderly progress of truth. I am aware, of course, that science may suggest simplification. The human mind turns, it seems, to simple explanations and broad generalizations. The specialist is ever prone to ride his hobby, to disregard what doesn't harmonize with his theory, to expand his explanations and to draw on his imagination. It often seems difficult to be conservative. Our minds run on ahead of our data. The result is we are prone to explain too much by our theories. The greatest difficulty before the research worker in agronomy, as in other fields, is to keep an open mind, to admit that he does not know, and to avoid too broad generalizations

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[1] Presidential address read at the annual meeting of the American Society of Agronomy, at Washington, D. C., November 20, 1930.

[2] Professor of Agricultural Chemistry, University of California, Riverside, Calif.

It is in the hope that I may contribute in some small measure to clearer thinking that I have prepared this address. It is my purpose to avoid unnecessary technicalities and, of course, I shall not attempt to cover the entire range of phenomena involved in the base-exchange question. Having been engaged almost exclusively in research on base exchange for many years I find some difficulty in deciding where to begin; the orthodox method is to review the literature This I shall reserve for another occasion.

At the outset it may perhaps be profitable to consider the question, "What do we mean by base exchange?" Base exchange obviously denotes an exchange of bases. As used by soil workers base exchange refers to the reaction which certain insoluble constituents of soils undergo when they are brought into contact with a salt solution. The cations of the salt solution are said to replace the bases from the soil. In reality the salt solution reacts chemically with certain constituents of the soil, with the resulting formation of two compounds, one of which is soluble and the other is insoluble. The base, added as a soluble salt, combines by exchange with the soil constituents, thus becoming insoluble in the salt solution, while the bases that are replaced from the soil pass into the solution and may then be leached out. It is the base of the soil that is replaced and not the base of the salt solution. The latter is the replacing agent.

A given base, such as calcium or potassium, when present in replaceable form, can be replaced by any one of various other bases. It is merely a matter of concentration. However, the base-exchange reaction obeys the law of mass action and chemical equilibrium. This means that only a part of the replaceable bases of the soil can be set free by a single addition of a salt solution. It is only as the soluble product of the reaction is absorbed by plants, leached away, or otherwise removed from the field of action, that the replacement of the bases can continue on towards completion. The result is that when we add a salt, such as is contained in certain fertilizers, only a part of the replaceable bases of the soil are acted upon. Conversely, only a part of the base that is added or applied as fertilizer becomes immediately absorbed by the soil.

Usually calcium comprises from 50 to 80 per cent of the total of all of the replaceable bases Magnesium stands next in amount, while normal soils contain only a small quantity of replaceable potassium and sodium

As stated already the replaceable bases can be replaced by the base of various salt solutions This fact has a direct bearing on the use of fertilizers When a given fertilizer is applied, more or less of the added constituents dissolve in the soil moisture The result is a comparatively concentrated solution of the fertilizer is formed around the particles of the applied fertilizer

If a soluble calcium salt is applied, such for example as superphosphate, very little base exchange takes place for the reason that the chief replaceable base of the soil is already calcium However, if a potassium salt is applied the conditions are very different The potassium replaces more or less calcium from that part of the soil with which it comes into immediate contact, with the result that an increase in soluble calcium is brought about without applying any calcium whatever At the same time a corresponding amount of the potassium passes from the form in which it was applied and becomes a part of the replaceable bases of the soil Rains falling later leach some of the remaining soluble potassium downward, thus bringing the potassium ions into contact with replaceable calcium lower down The consequence is that practically all of the added potassium finally becomes absorbed by the soil The applied potassium has itself become replaceable potassium and hence no longer soluble in water. The potassium is said to be fixed by the soil

The fixation of potassium by soil is a very striking matter Suppose, for example, we apply potassium chloride to the surface of a soil at the rate of 500 pounds per acre, and then add an excess of water. It will be found that the upper few inches of many types of soil will fix practically all of this potassium. In this case the roots of deep-rooted crops may not be able to come into contact with the applied potassium For example, in certain localities in California where prune trees are grown, Hoagland has found considerable difficulty in supplying the needed potassium owing to the intervention of the base-exchange principle. The applied potassium becomes fixed, as a result of base exchange, in the upper layers of the soil above the zone occupied by the roots of the prune trees.

It would be a mistake to conclude, however, that the potassium upon being fixed by base exchange is then totally unavailable for plant growth, for another factor of great importance gradually becomes operative. I refer to the fact that the replaceable bases of the soil are gradually set free by H ions. In fact acids are more potent in replacing the bases of the soil than are salts. This principle has much practical importance. The replacement of potassium by H ions has much to do with the availability of potassium to growing plants.

Suppose we are dealing with a soil which contains replaceable calcium, but no other calcium compound. When a plant is grown in such a soil more or less calcium will be absorbed by the plant. This is made possible through the intervention of H ions. The soil moisture always contains more or less carbonic and other acids formed by microbiological processes. The H ions of these acids react by ion exchange with the replaceable calcium, bringing the calcium into solution and thus making it available.

If the soil contains any considerable amount of replaceable potassium the H ions will replace potassium also. In fact, potassium that has been fixed and thus become replaceable, is more easily replaced by H ions than is calcium. Hence the H ions, formed around the roots of growing plants by carbon dioxide and by other processes, replace the fixed potassium, thus making potassium available to the plant.

These two phases of base exchange, namely, the fixation of potassium and the replacement of bases by H ions, are extremely important from the standpoint of plant growth. The fixing power of the soil for potassium prevents the loss of potassium through leaching by heavy rains, and the re-solution of the potassium through the replacing action of H ions brings the potassium back into solution as it is needed by growing plants.

Ammonium salts act very much as potassium salts. NH_4 is rapidly absorbed by soil owing to its power to replace the natural bases. Later the absorbed NH_4 gradually passes back into solution through the action of H ions. Nitrification then intervenes and gradually converts the ammonia into nitrate. The nitrogen thus passes from the form of a cation (NH_4) into the form of an anion (NO_3). Although the former is readily absorbed by base exchange, the latter remains permanently in solution, provided it is not absorbed by plants or transformed into other forms by microbiological processes.

When any soil base is replaced by H ions, whether it be calcium, mangesium, potassium, or NH_4, the soil will then contain an amount of H ions in replaceable form equivalent to the bases that have been replaced by H ions. Should the soil contain calcium carbonate this compound comes into play at this point, with the result that the H ions act on the calcium carbonate. The consequence is that the carbonate is decomposed and the H ions are neutralized. In this case the soil may remain alkaline or neutral. On the other hand, the conditions are very different where calcium carbonate is absent. In this case the H ions formed by biological processes and taken up by ion exchange, impart an acid reaction to the soil mass. When any considerable part of the replaceable bases have become replaced by H ions, the soil will give an acid reaction and may be too acid for economic crop growth. In this case the obvious remedy is to reverse the process and this can usually best be done by applying lime

Therefore, when lime is applied to an acid soil, one at least of the most important reactions which takes place is that of replacing the H ions from the exchange material of the soil Hence the application of lime to an acid soil involves the principle of base exchange in a very definite way. In fact soil acidity is largely a question of replaceable H ions and the replaceable H ions can be replaced by a base such as lime. When this has been done to a sufficient degree the soil is no longer acid

The reaction that takes place between H ions and the replaceable bases is important for another reason. It tends to keep down the H-ion concentration of the soil solution The acids formed by nitrification, sulfofication, etc , are highly ionized If it were not that these acids combine with the base-exchange material, the soil solution would soon become excessively acidic. The insoluble acid compounds formed by the absorption of H ions ionize much less than such acids as HNO_3 or H_2SO_4. The so-called buffer action of soils has to do chiefly with the replacement of bases by H ions.

One of the most striking and immediately important phases of base exchange is found in connection with alkali soils. In this case sodium salts, which so often accumulate in excessive amounts in arid regions, react by base exchange with the replaceable calcium of the soil. In certain cases the sodium may replace a very high percentage of the replaceable calcium, and where this is the case the soil will acquire peculiar properties in consequence. Successful reclamation of such soil involves more than drainage and the leaching out of the soluble salts. The sodium that is absorbed by base exchange must also be removed before the soil is a suitable medium for plant growth, for the insoluble sodium compounds that are formed by base exchange possess properties that are distinctly unfavorable to plant growth. These compounds hydrolize giving the soil a strongly alkaline reaction; they become hydrated and swell enormously when wet; the particles become pronouncedly deflocculated, sometimes to such an extent as to render the soil mass almost entirely impervious to air and water.

Where this is the condition the reclamation of an alkali soil must involve the replacement of the replaceable sodium by the calcium, as well as the leaching out of the soluble salts. Some of our most interesting field work in California has had to do with this matter. Formerly, it was thought that an alkali soil was simply a normal soil which contains an excess of soluble salts and that leaching coupled with drainage was the universal remedy. As a result of base-exchange investigations we have learned, however, that something more than leaching may be required. An alkali soil may need to be treated so as to restore calcium to its normal relationship in the base-exchange material. We have been able to demonstrate on a practical scale that this principle is applicable not only to important areas of alkali soil, but that in such cases successful reclamation must necessarily involve the replacement of sodium by calcium. We accomplish this exchange not necessarily by applying a soluble calcium salt, but by applying some material which will bring about the solution of the insoluble calcium carbonate of the soil. The calcium thus dissolved then effects the necessary changes in the base-exchange material. We have found sulfur to be especially useful in this connection.

Agronomists from humid regions sometimes give the impression that researches on alkali soils are entirely foreign to their interest, and that alkali soils are utterly different from acid soils. Base-exchange investigations have revealed, however, that this is not true. Although alkalinity and acidity are exactly opposite from a chemical point of view, soil acidity is closely related to the problem of important areas of alkali soil. In both cases very similar soil compounds are involved. With acid soils the normal bases, chiefly calcium, have been replaced by H ions; with alkali soils sodium has replaced the calcium, but with both alike it is the same soil components that have been adversely acted on. The remedy for the one is to replace the H ions with calcium by liming; with the other sodium must be replaced by calcium. As a matter of fact studies on alkali soils have contributed directly to a better understanding of soil acidity.

There are several other features of base exchange that have an agronomic interest but time will not permit their discussion at present.

At the outset I suggested that the importance of base exchange is sometimes abused by its friends. I can only indicate briefly wherein this abuse lies. In the first place, base exchange has nothing to do directly with phosphate and nitrate questions. Base exchange is concerned with cations and not with anions. Indirectly, phosphates may be involved through the precipitation as insoluble phosphates of the replaced bases, but the phosphate ion as such takes no part in the base-exchange reaction.

In the second place, the replaceable bases are by no means the only source of calcium and potassium which plants utilize in their nutrition. Calcium carbonate, if present, will supply the needs of plants for calcium. Other calcium compounds, such as calcium phosphate and various calcium silicates, may also supply notable quantities of calcium to the soil solution. Various potassium minerals are also involved in plant nutrition We are certainly not justified in saying that either replaceable calcium or replaceable potassium is the sole available form of these elements. Exchange reactions involving the replacement of bases by H ions, or by some other base, undoubtedly contribute to plant nutrition both directly and indirectly, but many substances not a part of the base-exchange material also make important contributions to plant growth and to the general properties of the soil.

In the third place, base exchange is not a universally important factor in connection with alkali soils, at least not to a marked degree. Many American alkali soil areas do not contain replaceable sodium in notable amount. Wherever calcium is an important constituent of the accumulated soluble salts the base-exchange material is not greatly affected by the sodium salts, and this is true even though the concentration of soluble sodium salts be extremely high. It is erroneous to conclude, therefore, that all alkali soils necessarily require special treatment directed toward the replaceable sodium. Many important alkali areas of the western states contain substantial amounts of soluble calcium and these are being reclaimed in a practical way by methods which do not act on the base-exchange material. In cases of this sort it is not necessary to apply sulfur, gypsum, or other materials which produce similar effects.

As I have already stated, where soluble calcium salts are either absent or present in low concentration and a high concentration of sodium occurs, the base-exchange principle is important. Generally speaking, it is only where sodium carbonate is present that replaceable sodium is a factor of pronounced agronomic importance in alkali soils. Where neutral sodium salts accumulate, the sodium, of course, tends to replace more or less calcium, but the principle of chemical equilibrium stops the reaction far short of completion, and the calcium that is replaced by sodium is likely to remain in the soil mass as a soluble calcium salt. If the soil solution is strongly alkaline, however, the replaced calcium is precipitated as carbonate and the action goes much nearer to completion.

I regret that time will not permit a full discussion of our more recent work on the specific nature of the base-exchange substances. These substances are of two kinds: organic and inorganic. My work has dealt chiefly with the latter. It has long been held that the replaceable bases are adsorbed on the surface of the colloidal particles, and certain workers have believed that the inorganic base-exchange material is of a zeolitic nature. Cur work has shown quite conclusively that neither of these views is tenable.

The base-exchange material is definitely crystalline and the crystals, ultra microscopic of course, contain replaceable base on their interior as well as their exterior. X-ray evidence strongly indicates that the substances in question belong to the true clay minerals and that they are not of a zeolitic nature. These clay minerals vary somewhat from soil to soil. The present indication is that the clay mineral first formed in the soil mass is closely related to the bentonitic clay known as montmorillonite. When this mineral undergoes prolonged weathering under humid conditions it seems to pass through a series of alterations mineralogically, but it nevertheless continues to be a clay mineral. The specific clay mineral that is responsible for the acidity of the Cecil series, for example, seems to be closely related to halloysite, which is a hydrogen aluminum silicate belonging to the kaolinite clays. Various of the clay minerals are structurally quite similar and none of them are closely related to zeolites. It seems certain that the base-exchange constituents are true chemical compounds and not adsorption compounds as was thought at one time.

Since the replaceable bases occur in the interior of the mineral particles as well as on their exteriors, it seems meaningless to assert that the replaceable bases are adsorbed on the surface of the colloidal particles of the soil. Rather the bases constitute an integral part of these particles.

Although the base-exchange reaction is chiefly confined to the colloidal material of the soil, the colloidal material is not necessarily amorphous. Both chemical and X-ray evidence agree in showing that the inorganic colloidal material of soils is largely crystalline but, as suggested already, the base-exchange material is not uniformly the same in all soils. In some of our western areas the base-exchange substance is primarily a magnesium compound, probably a magnesium alumino silicate. In other places it is a double magnesium potassium alumino silicate, while in the case of more strongly leached soils not only have the bases been replaced by H ions but an alteration has taken place in the ratio of SiO_2: Al_2O_3.

It seems safe to assert that base exchange is one of the important and widely applicable principles of soils, but, as stated at the outset, base exchange neither applies to, nor explains, everything about the soil. Its investigation has nevertheless given us a much better understanding of some very important aspects of soils. A good working knowledge of base exchange will certainly prove valuable to agronomists.

BREEDING CORN FOR RESISTANCE TO THE EUROPEAN CORN BORER[1]

A. R. MARSTON[2]

In 1921, the European corn borer (*Pyrausta nubilalis* Hbn.) was first found in Michigan. By the fall of 1925 this insect had spread over several southeastern Michigan counties and the possibilities of serious losses were becoming evident. At this time the insect was also wide-spread in Ohio (northern counties), Pennsylvania, New York, New England, and Ontario. In Ontario the corn borer was particularly destructive, causing great losses in Kent and Essex Counties just across the Detroit River from Wayne and Monroe Counties, Michigan.

In order that more might be learned of the European corn borer under Michigan conditions, the State Board of Agriculture in 1926 leased land near the city of Monroe for the establishment of an experiment station at which problems having to do with the European corn borer and its control might be studied. Since that time the agronomic work at this sub-station has been carried on by the writer.

One of the first efforts at the Monroe station was the search for strains of corn which might be distasteful, repellent, or in some way not subject to attack or serious injury by the corn borer. Plant breeding effort has contributed varieties of plants which are resistant and in some instances essentially immune to plant diseases. That plant varieties can be developed which are resistant to attack by insects is not without possibilities.

Since the beginning of the work at Monroe other investigators have reported promising results in their search for corn borer resistant strains. Roubaud[3] of the Pasteur Institute, Paris, reports studies in 1927 which indicated seemingly complete immunity of the corn variety Dent de Cheval and partial resistance of the variety Hatif d'Auxonne to infestation by the corn borer. Hase[4] of the German Biological Institute of Agriculture has also noted the practical immunity of the variety Pferdezahn under conditions very favorable to corn borer attack. Both these investigators foresee the possibility of producing corn varieties resistant to the corn borer. By the work in plant breeding at this station, it is hoped that a variety of corn may be developed that will be at least partially resistant to the attack of the European corn borer and at the same time as high in yield, as early in maturity, and as desirable in every other respect as the standard Michigan varieties of corn.

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[1] Contribution from the Farm Crops Section, Michigan State College, East Lansing, Mich. Journal Article No. 42 (N. S.). Received for publication June 19, 1930.

[2] Agronomist, Michigan State College Corn Borer Sub-Station, Monroe, Mich.

[3] ROUBAUD, E. Resistance of various corn varieties to corn borer infestation. Intern. Corn Borer Invest., Sci. Rpts., 1927–1928. Published by International Livestock Exposition, Union Stock Yards Chicago, Ill.

[4] HASE, ALBRECHT. From report published in International Corn Borer Investigations. Sci. Rpts. Vol. II.

In this work selections have been made from a large number of in-bred strains and crosses of standard corn varieties from Michigan, Ohio, Wisconsin, Minnesota Indiana, and Illinois In addition, a South American type of corn known as Maize Amargo has been crossed with some varieties commonly grown in Michigan. Studies of the physiological and chemical characteristics of these different strains have been made in an effort to determine possible reasons for any preference which the corn borer might show. The physiological characteristics studied included fibro vascular bundle counts, epidermal hardness and thickness, size of stalk in relation to its height, and width and number of leaves. In the study of chemical characteristics, the acidity and sugar content in the various stages of development of the corn plant were determined.

In all the native strains of corn studied there were no significant differences in infestation which might justify a belief that these varieties were resistant to corn borer attack. However, more promising results were secured from the work with the South American corn (Maize Amargo) which was furnished this station in 1926 by Dr. D W. Jones of the Federal Corn Borer Station, Arlington, Massachusetts, upon the suggestion of Dr. F. J. Carey of the U. S. Bureau of Entomology. This Maize Amargo, when tested at the Arlington Station, indicated probable resistance to the corn borer, but to provide assurance that this resistance would manifest itself under Michigan conditions, one hill of this variety was covered with a small cage and 25 mature corn borer larvae were placed on the leaves of the plants. Observations were made some time later by Dr. Phillip Luginbill of the U. S. Bureau of Entomology, then at this station, to see if the borers had established themselves on the plants, but he was unable to find a single borer.

The following year, 1927, a large cage in which a number of corn borer moths were liberated, was placed over several of the Maize Amargo plants. Similarly, large cages were placed over native corn plants and the same number of moths placed therein. The corn borer moths caged with Maize Amargo deposited a large number of their eggs on the cage structure, but only about 150 eggs were laid on the Maize Amargo plants, and when this corn was mature but one live corn borer could be found. At the same time the moths in the other cages deposited great numbers of eggs on the native corn plants and under these conditions the corn plants were completely destroyed.

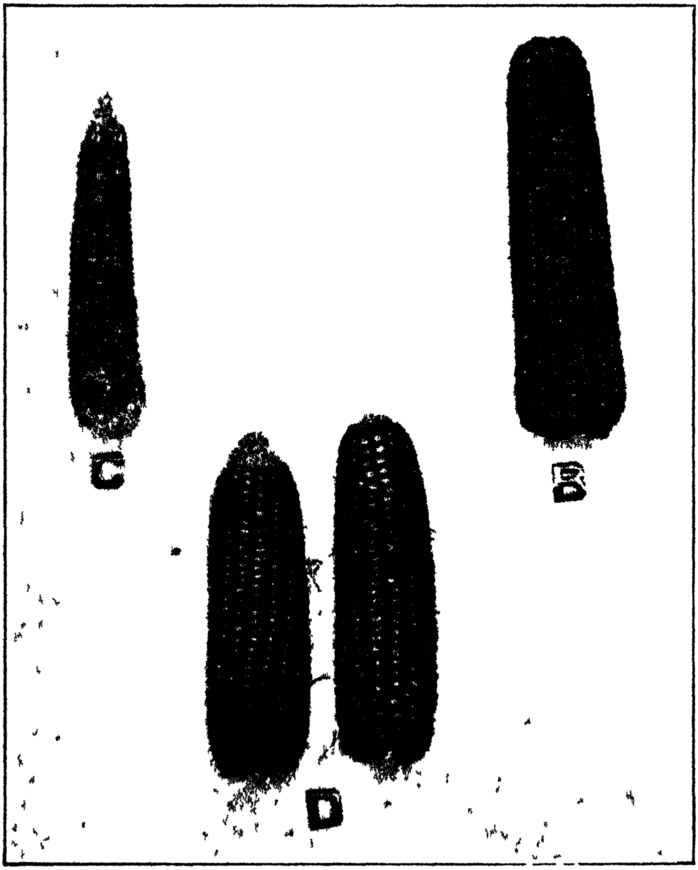

FIG 1 —Ears of the parents and progeny of Golden Glow and Maize Amargo corns C, Maize Amargo; B, Golden Glow, D, ears harvested from a non-infested, F_1 in-bred strain of Golden Glow x Maize Amargo

In 1926, Maize Amargo was crossed with three strains of Michigan corn, *viz.*, Duncan, Golden Glow, and Red Cob Ensilage The Maize Amargo, a very late maturing corn, entirely unadapted to the northern part of the United States, silked and produced pollen much later than the Michigan varieties. This presented difficulties in making this cross. When the crosses were made at this station, Maize

Amargo, heavily fertilized with superphosphate to speed it to maturity, was used as the male parent, with Duncan, Golden Glow (Fig. 1), and Red Cob Ensilage as the females. A few kernels of each cross were secured. A portion of this hybrid material was furnished to F. D. Richey of the U. S. Bureau of Plant Industry, and the balance retained at this station for further work.

The seed retained at Monroe was planted the following year (1927) and only two plants of the Duncan x Maize Amargo, four plants of the Golden Glow x Maize Amargo, and nine plants of the Red Cob Ensilage x Maize Amargo grew. This being the first generation and there being such a limited number of plants, most of them were covered with screened cages in order to protect them from possibility of injury.

In 1928, all the hybrid seed harvested was planted, giving a large number of plants with which to work. Along with this F_2 generation a few rows of each of the parent varieties were planted. All these plats were planted at the same time, and all F_2 plants grew to a normal height. Infestation counts were made on all these plats by C. B. Dibble of the Entomology Section of this station, the counts being based on the number of plants which he found infested and the number non-infested in each plat. The results are given in Table 1.

TABLE 1.—*Infestation of Maize Amargo and Michigan corn varieties compared with their F_1 and F_2 progenies.*

Variety of corn	Infestation %
Maize Amargo (male parent)	5
Polar Dent (female parent)	48
Polar Dent x Maize Amargo F_1	38
Polar Dent x Maize Amargo F_1	33
Polar Dent x Maize Amargo F_1	29
Duncan Yellow Dent (female parent)	68
Duncan x Maize Amargo F_2	18
Duncan x Maize Amargo F_2	8
Golden Glow Yellow Dent (female parent)	39
Golden Glow x Maize Amargo F_2	8
Golden Glow x Maize Amargo F_2	5
Golden Glow x Maize Amargo F_2	3
Golden Glow x Maize Amargo F_2	5
Red Cob Ensilage (female parent)	54
Red Cob Ensilage x Maize Amargo F_2	23
Red Cob Ensilage x Maize Amargo F_2	5
Red Cob Ensilage x Maize Amargo F_2	14
Red Cob Ensilage x Maize Amargo F_2	24
Red Cob Ensilage x Maize Amargo F_2	13
Red Cob Ensilage x Maize Amargo F_2	13
Red Cob Ensilage x Maize Amargo F_2	4
Red Cob Ensilage x Maize Amargo F_2	15
Red Cob Ensilage x Maize Amargo F_2	15

In 1927, crosses were made between Maize Amargo and Polar Dent, Clements White Cap, and other Michigan dent varieties. According to Table 1, it is noteworthy that the Michigan parent variety showed a fairly high infestation, while the cross of these same varieties with Maize Amargo in the F_2 generation carried a markedly lower infestation (Fig. 2) However, the crosses between Polar Dent and Maize Amargo in the F_1 generation were practically as high in infestation as the Michigan parent variety (Polar Dent). The low infestation in these F_2 in-bred plats of the crosses indicate that a segregation for susceptibility and resistance to corn borer attack was taking place, and that some plants in these plats very likely were highly resistant to corn borer infestation. As the infestation of normal corn at this station was not 100%, some plants of the crossed material were not attacked merely by chance, and such non-infested plants could not be selected with assurance that they carried any inherent resistant characteristics. The mark-

FIG. 2.—The row under observation was one of the non-infested plats, while in the adjacent plat to the right 29% of the plants were infested and in the one to the left 26% were infested

edly lower infestation of the F_2 hybrids, however, appeared to be significant. Accordingly, by hand pollenization, all plants in these plats were in-bred for use the following year in planting each family in a separate row. In the F_3 generation, planted in 1929, some of these plats scattered throughout the field carried no borer infestation, while adjacent plats were infested.

Table 2 shows three different groupings of plats as examples of what was found throughout the field.

Table 2.—*Comparison of infestation between adjacent plats of F_3 in-bred strains, 1929.*

Plat No.	Variety	Infestation %
90633	Duncan x Maize Amargo F_3	29
90634	Duncan x Maize Amargo F_3	0
90635	Duncan x Maize Amargo F_3	26
90778	Duncan x Maize Amargo F_3	41
90779	Duncan x Maize Amargo F_3	0
90780	Duncan x Maize Amargo F_3	22
90965	Golden Glow x Maize Amargo F_3	0
90966	Golden Glow x Maize Amargo F_3	22
90967	Golden Glow x Maize Amargo F_3	0

The non-infested rows, similar to the ones shown in Table 2 gave no external indications to which their infestation or lack of infestation might be attributed. Some were taller than the adjacent rows and some were shorter; some were earlier, others later; all had been planted at the same time, yet along with the rows of no infestation were rows in which as many as 50% of the plants were attacked

One group of Golden Glow x Maize Amargo crosses never possessed the vigor of the rest of the F_3 hybrids. For some reason, the stand was poorer, the plants were slow in developing, and few of them ever attained a height of 3 feet. Slow-growing or late-planted corn is less attractive to corn borer moths than vigorous corn. Possibly because of lack of vigor there was hardly any infestation in this group.

If, because of its abnormalities, we may exclude this group from consideration, the balance of the F_3 plats, in-breds of Duncan, Golden Glow, and Red Cob Ensilage crosses with Maize Amargo, numbered 935 families in all of which 708 were found to have corn borers present and 227 were without any borers.

Since this F_3 generation planting was on a single row basis, it is unlikely that entire rows would be uninfested from chance alone when adjacent rows were severely attacked. The ratio of 708 families infested to 227 non-infested is 3.1:1. Therefore, the data accumulated thus far indicate that the evident resistance of Maize Amargo to corn borer attack is a simple Mendelian character recessive to that characteristic of standard Michigan corn varieties which makes them subject to heavy attack and severe damage. What this character may be furnishes a problem for future study. The in-bred material from these F_3 non-infested plats will be used in an attempt to produce a strain of corn resistant to borer attack, and carrying characteristics of quality and productivity so that it may be grown profitably in corn borer infested areas.

Since 1926, successful crosses have been made between Maize Amargo and several other varieties of corn, and these are being handled in the same manner as the crosses previously described. A cross made in 1928 between Maize Amargo and Golden Bantam sweet corn is of considerable interest. In 1929, the F_1 generation of this cross grew to an average height of 8 feet with very few suckers and showed a definite segregation on the ear of a 3:1 ratio of flint and sweet corn kernels, thus proving that the cross was successful. Crosses have been made between Maize Amargo and eight-rowed Flint, and Maize Amargo and Northwestern Dent, these being earlier types of corn adapted to northern localities. Michigan Hulless pop corn was also crossed with Maize Amargo and this cross yielded nine kernels which will be used in further breeding work.

THE COMPARATIVE DROUGHT RESISTANCE OF SORGHUMS AND CORN[1]

JOHN H. MARTIN[2]

The ability of sorghums[3] of both grain and forage types to resist drought has long been known. Cates (2)[4] has applied the name "crop camel" to kafir (one of the grain sorghums) because the plants can stand for considerable dry periods without apparent suffering from a deficiency of moisture. The following quotation from Fields (4) presents in a forceful manner the opinion of a farmer regarding the drought resistance of kafir:

> "J. B. Adams of El Dorado, Kans., who has had much to do with establishing kafir corn as a real crop in Butler County, said, 'It (1911) was a season of unusual severity, the dryest and hottest in Kansas, as it was in Oklahoma since 1901. A pitiless sun burned up the Indian corn and parched the native grass upon the prairies. Throughout this trying ordeal, our unfailing friend, the hardy and indomitable kafir, stood sentinel upon the prairies with the patient fortitude inherent in its nature, born of centuries of hardship upon the desert; it bided its time and silently waited for rain, springing triumphantly into new life with the first downpour from heavens. Our prairie hay turned out less than a third of a crop and our alfalfa only a little better than half a crop. But notwithstanding this accumulation of calamities, we pushed back the impudent face of famine, cheated the hot winds, and whipped the drouth to a standstill with kafir corn.' "

The marked superiority of sorghums over corn in the dry southwestern states makes the comparison a useful one in studies of drought resistance. The corn plant is similar to sorghum in size, appearance, season, and type of growth. The two crops often are grown on the same farm and by identical methods. The grain sorghums directly compete with corn as a grain crop.

Most of the grain sorghums are grown where the climate is too dry and hot for successful corn production. The zone of transition between the predominating acreages of corn and grain sorghum in Kansas lies approximately along the line of an annual precipitation of 25 inches. Where grain sorghums are grown to a considerable extent under conditions of higher rainfall, as in southeastern Kansas and southwestern Missouri, the soil usually is shallow and incapable of holding ample moisture for a good crop of corn.

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication July 21, 1930.

[2] Senior Agronomist.

[3] *Holcus sorghum* L.; *Sorghum vulgare* Pers.; *Andropogon sorghum* Brot.

[4] Reference by number is to "Literature Cited," p. 1003.

The grain sorghums also are important in several irrigated valleys of southern California and Arizona where the extreme heat and low humidity appear to be unfavorable for corn production.

The numerous phases of the resistance to and endurance of drought and the evading of and escaping from drought by all types of plants have been reviewed by Kearney and Shantz (6) and by Maximov (10) and will not be discussed here. In the present paper the term "drought resistance" is used loosely to refer to all characteristics which enable sorghum plants to survive or produce grain under unfavorable moisture conditions. Certain characters of corn and sorghums which might have a bearing on the relative drought resistance of these crops have been studied during the past four years and are reported here. Results obtained by other investigators in studies of the comparative drought resistance of corn and sorghums also are considered, with relation to known differences in the characteristics or behavior of the two crops.

MORPHOLOGICAL DIFFERENCES

In a xerophyte, according to Maximov (10, p. 374), "there is a decrease in the size of all cells (including the stomata), a thickening of the cell walls, a strong development of palisade mesophyll, a denser network of veins and an increase in the number of stomata."

Microscopic examinations of the leaves of sorghums and corn grown under identical conditions have shown smaller cells and stomata in the sorghums, the stomata in sorghums being about two-thirds the length of the stomata of corn. Appreciable differences in the actual thickness of the cell walls or in the palisade mesophyll were not apparent. The number of stomata per unit of area on either the upper or lower leaf surface is more than 50% greater in sorghums than in corn.

Average numbers of stomata within a given field of a microscope on leaves of about the same age and position on the stalk taken from plants grown in the greenhouse at Arlington Farm, Rosslyn, Va., in 1929 are shown in Table 1.

TABLE 1.—*Number of stomata within the same field of a microscope on leaves of two varieties each of grain sorghum and corn.*

Crop and variety	Average number of stomata in equal areas Upper leaf surface	Lower leaf surface
Grain sorghum:		
Sunrise kafir	400	450
Dwarf Yellow milo	280	340
Corn:		
Reid Yellow Dent	130	210
Northwestern Dent	140	200

In both corn and sorghums the upper leaf surface usually contains only about two-thirds as many stomata as the lower leaf surface. The leaves of sorghums have no hairs except at the base. Scattering hairs are found on the upper surface of corn leaves, but these are too few to affect radiation or evaporation appreciably.

Corn leaves have small groups of hygroscopic or motor cells at intervals on the upper leaf surface which lose water rapidly and cause the leaf to roll up under drying conditions. Large groups of hygroscopic cells in sorghum leaves occur in single rows along each side of the midrib and usually cause the sorghum leaf to fold up instead of roll, as does the corn leaf. Small groups of hygroscopic cells in sorghum leaves permit rolling also when the folding is incomplete. The larger number of motor cells in the group which quickly collapse upon drying cause the folding of sorghum leaves to take place much more rapidly and completely than the rolling of corn leaves.

The most significant differences between the leaves of sorghums and corn which might influence evaporation are found on the epidermis. The blades and sheaths of the leaves, as well as the peduncle, of growing sorghum plants are coated with a heavy bloom of white wax. Microscopic examination of cross sections of the epidermis of both the leaves and culms, treated with 60% sulfuric acid, shows a more completely cutinized layer on sorghum than on corn plants. The wax and the cuticle are believed to be the principal factors in limiting evaporation from sorghum plants.

Miller (11) has shown that the number of small roots in sorghums is about twice as large in proportion to leaf area as in corn. He assumes that this might be a factor favoring in sorghums the maintenance of a balance between water absorption and transpiration.

PHYSICAL DIFFERENCES

OSMOTIC PRESSURE

Maximov (10), reviewing the work of numerous investigators, states that, in general, xerophytic plants are characterized by a higher osmotic pressure of the cell sap than mesophytes. Keller (7) and Eaton (3) have shown that an increased osmotic concentration reduces the rate of transpiration or evaporation from leaves.

Joint investigations by the writer and others of the osmotic pressure and electrical conductivity of the tissue fluids of sorghums and corn were carried out at Sacaton, Ariz., during the seasons of 1926 to 1929, inclusive. The results obtained are summarized and reported in a recent paper by Martin, Harris, and Jones (9). The average freezing-point depression of the leaf juices of sorghums was about

1° C, which is equivalent to an osmotic pressure of approximately 12 atmospheres. Corn leaf juices had a higher osmotic pressure than those of the sorghums. The internode juices of sorghums had average osmotic pressures of approximately 15 to 20 atmospheres, while the corn stalk juices had an average osmotic pressure of about 14 atmospheres. These values are rather too low to place sorghums among the true xerophytes on the basis of osmotic concentration.

The osmotic pressure of the juice of the crowns of sorghum plants was slightly higher than that of corn. The osmotic pressure of the juice of the roots of sorghums was from 20 to 100% higher than in corn during the period from flowering to maturity. Red kafir roots in four determinations had osmotic pressures of 12 to 15 atmospheres, while two varieties of corn showed osmotic pressures of 9 to 11 atmospheres. Sorgo roots have a still higher osmotic pressure than kafir. Osmotic pressure differences in the leaves, therefore, could not account for any superior drought resistance of sorghums, but the higher osmotic concentration of the juices of the stalks, crowns, and roots of sorghums, especially the latter, might aid the sorghum plants to resist dessication and death for a longer period.

The higher osmotic concentration of sorghum stalks and roots apparently is due to a greater accumulation of sugars in sorghum than in corn.

The osmotic concentration of the leaf juices in sorghums decreased from the top leaf downward. The lower leaves dry out first on plants subjected to deficient soil moisture, and the difference in osmotic pressure might account in part for this difference in drying.

IMBIBITION

Determinations of "bound" water made by the writer failed to show definite indications of the presence of hydrophilic colloidal material in the juices of the leaves and stalks of either sorghums or corn (9). Apparently, characters other than that of imbibition by the colloidal protoplasm must account for the greater drought resistance of sorghum as compared with corn.

MOISTURE CONTENT

Results of moisture content determinations of grain sorghum and corn plants grown on irrigated land in the dry climate at Sacaton, Ariz., in 1928 and 1929, are shown in Table 2. The leaves contained considerably less moisture than the stalks. The leaves of Reid Yellow Dent corn and Dawn kafir contained the most moisture. The corn stalks contained more moisture than the sorghum stalks. The samples in any one test were gathered at the same time, but the

TABLE 2.—*Moisture content of plants, culms, and leaves of grain sorghums and corn at Sacaton, Ariz., in 1928 and 1929.*

Variety	Moisture content										
	Whole plants			Culms, 1928		Pith			Leaves		
	1928	1929	Average	Leaves removed	Leaves and sheaths removed	1928	1929	Average	1928	1929	Average
	%	%	%	%	%	%	%	%	%	%	%
Dawn kafir	80.5	81.2	80.9	82.3	83.4	79.9	84.1	82.0	77.1	76.3	76.7
Dwarf yellow milo	80.7	82.3	81.5	83.1	84.4	82.2	83.5	82.9	73.0	72.6	72.8
Standard feterita	81.1	78.8	80.0	84.5	83.3	78.7	83.6	81.2	72.5	73.8	73.2
Sacaton June corn	83.1	84.1	83.6	87.1	88.9	82.4	81.1	81.7	73.6	71.2	72.4
Reid Yellow Dent corn	86.2	86.5	86.4	91.3	92.2	84.2	83.1	83.6	77.6	76.9	77.3

samples for different tests were gathered at various times of the day. Owing to differential wilting the relative position of the varieties might change during the day, as shown by Miller (14).

PHYSIOLOGICAL DIFFERENCES

TRANSPIRATION

Briggs and Shantz (1) and Shantz and Piemeisel (16), working in northeastern Colorado, and Miller (12), working in southwestern Kansas, showed sorghums to have a lower transpiration ratio than corn. Kiesselbach (8), at Lincoln, Nebr., on the other hand, found an opposite difference in the transpiration ratio under conditions more favorable for the growth of corn than of sorghums. The transpiration of both crops at Lincoln was much lower than in the Colorado and Kansas experiments, and evidently the transpiration rate of sorghums is lower than that of corn only under conditions of high evaporation.

In the Great Plains area, however, where drought resistance is an important factor in the adaptation of sorghums, more water is evaporated from a corn plant than from a sorghum plant of the same weight, growing under identical conditions with the soil well supplied with water. This proves that the sorghum plant is better equipped to retard high transpiration than is corn. The difference must be due either to a reduced leaf area per plant or to a mechanism which limits evaporation from the leaf surface, or both Miller and Coffman (15) showed that sorghum plants had a smaller leaf area per plant than corn. In their experiments the amount of water transpired per unit of leaf area was greater in sorghums than in corn apparently because the corn plants could not take up water from the soil rapidly enough to maintain the water supply in the leaves. Miller (13) showed that corn varied more in moisture content during the day than did milo or kafir, and that the corn wilted more. Miller's experiments were conducted under favorable soil moisture conditions. When soil moisture is deficient or when severe hot drying winds occur, and both sorghums and corn are unable to absorb sufficient moisture, then differences in wilting become very apparent. The differences in wilting can be partly or largely explained by the different behavior of corn and sorghum tissues subjected to drying.

EVAPORATION FROM PLANT TISSUES

Experiments to determine relative rates of drying of the plants of sorghums and corn were conducted at Sacaton, Ariz., in 1928 and 1929. The plants were brought from the field and weighed immediately and at intervals thereafter, the plants being hung up in the shade in the meantime. The cut ends of the stalks were sealed with paraffin to prevent loss of water through the cut. The drying conditions under which each experiment was conducted were not entirely comparable, except for the whole plants and the culms with the leaves removed in 1928. The results are given in Table 3.

TABLE 3.—*Percentage of original weight of plants, culms, and leaves of sorghums and corn after drying in the open at Sacaton, Ariz.*

	Percentage of original weight after drying							
	Whole plants (24 hours)			Culms, 1928 (24 hours)		Leaves (11 hours)†		
Variety	1928	1929	Average	Leaf blades removed	Leaf blades and sheaths removed*	1928	1929	Average
Dawn kafir	73.0	75.7	74.4	75.8	86.6	55.8	74.2	65.0
Dwarf Yellow milo	72.6	72.5	72.6	72.6	87.4	43.3	61.1	52.2
Standard feterita	63.0	67.3	65.2	67.7	81.8	39.8	53.3	46.6
Sacaton June corn	55.9	66.0	61.0	66.0	86.9	38.8	52.1	45.5
Reid Yellow Dent corn	58.5	65.1	61.8	65.2	83.2	36.7	52.1	44.4

*Experiments begun five days later than where leaf blades alone were removed.
†8 hours in 1929.

Leaves dry much more quickly than whole plants and the loss in the weight of a stalk is more rapid with the leaves attached than when detached. The most important fact presented in Table 3 is the more rapid drying of the corn plants and tissues as compared with sorghums. This applies to both the culms and leaves. These results are confirmed by the slow rate of curing of sorghum stalks after harvest commonly experienced by agronomists and farmers. The difference in drying probably explains, to a large extent, the better drought resistance of sorghums. When sorghums and corn are subjected to conditions of limited soil moisture and high evaporation, both crops begin to wilt. Wilting at first occurs only during the heat of the day and the plants recover their turgor at night. Corn shows evidence of wilting earlier in the day than do sorghums. As moisture becomes more deficient, wilting becomes more severe and prolonged until recovery is incomplete at night. During a severe hot wind, permanent wilting may occur even with a fair amount of soil moisture present. The leaves and stalks of sorghum wilt less and can thus withstand longer and more severe drought before the tissues are desiccated beyond recovery (6). Growth can not continue during a water deficiency in the cells, and the plants remain dormant. Sorghum plants can remain dormant during a longer period than corn plants because their tissues are not so completely dried.

The data in Table 3 indicate that moisture is retained in the tissues of kafir longer than in feterita or milo. This conforms with the common observations that kafir can remain dormant and alive longer than the other grain sorghums. Milo and feterita are likely to be forced into fruiting, as moisture becomes limited, and will produce small heads, while kafir produces heads only after a rain comes.

The causes of the difference in drying rate between corn and sorghum tissues must depend either upon the internal cell organization or upon the external layers of the plant. As previously shown, the difference, at least in the leaves, does not depend upon differences in osmotic concentration of the cell sap and apparently not upon imbibitional properties of the protoplasm. This would indicate that the difference is due to better protection against evaporation by the cortical or epidermal tissues. That this is the case is indicated strongly by the results shown in Table 4 in which sections of sorghum and corn internodes sealed at the ends were subjected to drying in desiccators. After 25 hours of drying the sorghum culms had lost some weight but less than the corn sections. When the cortical tissues were removed, however, the sorghum sections dried very rapidly, much more rapidly than the corn, probably partly because of the smaller diameter of the sorghum stalks.

A similar reaction has been observed in leaves. Small pieces of sorghum leaves have been kept in the laboratory for several hours without appearing to be badly wilted. When a portion of a leaf blade is split tangentially or the cuticle removed, however, the sections dry out in a few minutes.

TABLE 4.—*Average percentage of original weight of unpeeled and peeled culms of sorghums and corn after drying in a desiccator for 25 hours.*

Variety	Percentage of original weight of culm	
	Not peeled	Peeled
Reed kafir	84.5	20.1
Dwarf Yellow milo	87.0	25.7
Reid Yellow Dent corn	80.0	48.4

The stomata on both sorghum and corn leaves close up within a few minutes after drying begins and long before wilting becomes apparent. The stomata remain closed until the tissue is so nearly completely dried out that the guard cells collapse. Most of the evaporation, therefore, takes place directly through the epidermal cells. As previously mentioned, the structural difference which probably accounts for the slower evaporation in sorghums is the wax and cuticle on the epidermis. In order to check the importance of such a structure, specimens of prickly pear cactus (*Opuntia* sp.) having an extremely thick and waxy cuticle were gathered and weighed. Like those of sorghums and corn the stomata of cactus also were closed during drying. After 48 hours of drying in the air at Sacaton, Ariz., the cactus leaves had lost only 4% of their original weight. Peeled specimens, on the other hand, lost nearly 87% of their weight. These cactus leaves contained large quantities of gelatinous material probably colloidal in nature. Gortner (5, p. 217) has shown that prickly pear leaves have a high imbibitional power and can withstand drying and later absorb enough water from a saturated atmosphere to start growth. Nevertheless, the colloids were incapable of retaining water against the forces of evaporation after peeling and the thick waxy cuticle is largely, if not almost entirely, responsible for the cactus plants remaining succulent during dry periods.

Another factor probably of less importance in reducing evaporation in sorghums is the rapid folding of sorghum leaves in comparison with the less rapid and less complete rolling of corn leaves. This may be observed either on or off a plant. The folding frequently takes place within a few minutes after removing a leaf from a plant. A completely folded leaf placed with the cut base in water will open up fully within an hour.

DORMANCY

The writer believes that a sorghum stalk recovers from a dormancy induced by drought chiefly because it has not wilted beyond recovery. Whether sorghum tissues will withstand greater wilting than corn and still recover has not yet been determined. The leaf tissues of both crops apparently are permanently wilted if air bubbles enter the cells. A factor of great importance in sorghums, however, is the dormancy of the basal buds during a drought and their rapid development into tillers or "suckers" after moisture becomes available. Frequently the suckers have produced a good crop of grain after the main stalks have died from extreme drought. Corn plants, even of suckering types, apparently lack the ability to develop fruitful tillers after the main stalks have perished from drought. The viability of the tiller buds of sorghum plants may be maintained partly because of the slow drying of sorghum stalks. The relatively higher osmotic concentration of the juices of sorghum crowns and roots as compared with corn may be of some importance. A short drought followed by rains usually causes a temporary dormancy in the sorghum stalks which already have developed, while a prolonged drought followed by rains kills the old stalks but still permits a crop of "suckers" to develop.

Kearney and Shantz (6) suggest that the slow growth of sorghum plants during the early season helps conserve the soil moisture which is needed later.

DROUGHT ESCAPEMENT

The discussion thus far has been confined chiefly to differences in drought resistance between corn and sorghums. Within the sorghum group are differences both in drought resistance and the ability to partly escape drought injury. The kafirs as a group probably are the the most drought-resistant of the grain sorghums from the standpoint of resisting desiccation of their tissues. They are among the least able to produce a crop of grain under adverse moisture conditions, however, unless the delayed rains come in time for kafir to head and mature a crop. This situation seems to be due to the extreme dormancy, the greater leafiness, and to the reduced tillering of kafirs. Milos, feteritas, and kaoliangs tend to produce small heads and a little grain in very dry seasons. Kaoliangs and feteritas and Freed sorghum are extremely early, very sparsely leaved, and are able to produce some grain with very little moisture. In these early varieties the grain is formed before the moisture supply is completely exhausted. Dawn kafir yielded an average of 39.8 bushels per acre during the wet years at several stations in the Southern Great Plains and 10.1 bushels per acre during the dry seasons at these stations. Standard feterita yielded an average of only 34.7 bushels during the wet seasons but outyielded the kafir, producing 12.9 bushels per acre during the dry seasons. This shows how the ability partly to escape drought is advantageous in dry seasons even for relatively drought-resistant crops.

SUMMARY

Grain sorghums, because of their superior drought-resistance, largely replace corn in the Southwest where the average annual precipitation is less than 25 inches.

Sorghum leaves have more stomata per unit of area and smaller stomata than corn leaves, sorghums in each case showing typical xerophytic characters.

Sorghum leaves and stems have a waxy and cutinized epidermis which reduces evaporation. Sorghum plants are less leafy than corn plants and have more secondary roots.

The osmotic concentration of leaf juices is lower and that of the stalk, crown, and root juices is higher in sorghums than in corn.

Sorghum stalks have a lower moisture content than corn stalks.

Sorghum has a lower transpiration ratio than corn under conditions of high evaporation.

Sorghum leaves and stalks wilt and dry more slowly than those of corn. The slower drying permits sorghum plants to withstand drought longer than corn and they may subsequently recover when moisture becomes available. The waxy cuticle apparently is largely responsible for the slow drying of sorghums. It is believed that the sorghum stalk recovers from a dormancy induced by drought chiefly because it has not wilted beyond recovery.

Sorghum plants can send up tillers and still produce a good crop if rains come after the main stalks have been killed by drought.

Early types of grain sorghum sometimes partly escape drought and produce some grain before the soil moisture becomes exhausted when kafir is a complete failure.

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PEANUT BREEDING[1]

W. E. STOKES AND FRED H. HULL[2]

Peanuts are becoming a crop of some importance in many southern states. Their average annual farm value in the United States for the past few years is in round numbers about $50,000,000. To this figure may be added the value of the vines and roots for feed and for soil improvement. It may be confidently predicted that the acreage of peanuts will increase, for they may be grown successfully on medium or low-priced land. Also, the demand for manufactured peanut products continues to increase, and in addition, new products of various kinds are continually being placed on the market. About 80,000,000 pounds of peanuts are imported annually into this country.

Approximately 63% of the peanut acreage is harvested and the nuts sold as a cash crop, the remainder being grazed off by hogs. Since the greater part of the harvested crop is manufactured into products of luxury or semi-luxury type, quality is of first importance. This is evidenced by the fact that No. 1 peanuts are frequently quoted at a 20% advance in price over No. 2's. There is a distinct need at present for improved varieties which will produce nuts of superior quality. Also, as the peanut industry expands the demand for varieties adapted to varied conditions and to more varied uses will also increase.

Peanuts have not received much attention from plant breeders in America, but it is probable that more attention will be given to peanut improvement in the near future. Since the information available upon peanut breeding is widely scattered and not easily accessible, it seems desirable to summarize previous papers and present a preliminary report of the breeding work in progress at the Florida Agricultural Experiment Station.

REVIEW OF LITERATURE

The earliest work reported on peanut breeding was done by Van der Stok (12)[3] at the Sugar Breeding Station in Java.[4] He made plant selections in several native and introduced varieties. By determining the average seed weight, shelling percentage, and number of seeds per nut, he was able to demonstrate the existence of several pure lines in each of a number of varieties. He states that the structure of the flower necessitates self-pollination and that cross-pollination very rarely occurs. He reports the results of two crosses, one between a variety having dark red seed coat and a variety having light red seed coat. The first generation gave all dark red seed. In the second generation there were about three times as many plants with dark red seed as with light red seed. A cross of a variety having small thin hulls with a variety having larger, thicker hulls gave a great variety of types in the second generation. Also, a new type with somewhat beaded hull appeared.

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[1] Contribution from the Department of Agronomy, Florida Agricultural Experiment Station, Gainesville, Fla. Received for publication June 30, 1930

[2] Agronomist and Assistant Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 1019.

[4] Thanks are due Dr. R. M. Barnette for the translation of Van der Stok's paper.

Badami (1, 2, 3, 4) reports considerable work on hybridization with peanuts, beginning with a natural hybrid of Spanish and Big Japan. The second generation consisted of four plants, one erect and three trailing. The erect plant had dark green foliage like the trailing parent. Its progeny were all erect. Of the trailing plants one gave a few erect progeny. From the progeny of the erect F_2 plant a new strain was selected. It is described as erect, hardy, produces nuts at base of plants, with pods mostly three seeded, as large as Virginia, and thick shelled. It ripens nearly as early as the common bunch varieties and is practically free of the leaf-spot disease.

Badami (2, 3, 4) also reports many artificial crosses. He first made a number of crosses between Small Japan and Virginia which he found to differ in the following main characters:

	Small Japan		Virginia	
1	Bunch type	-t	Trailing type	-T
2	Small pods	-p	Big pods	-P
3	Red seed coat	-R	Rosy seed coat	-r
4.	High per cent of oil		Low per cent of oil	
5	Early type		Late type	
6	Pale green leaf	-g	Dark green leaf	
7	Short nodes		Long nodes	
8	Short stalked flowers		Long stalked flowers	

Badami considered big pods and dark green leaves desirable, while color of the seed coat and erectness were considered less important. Later, he reports a number of segregates under observation, some of which appear very promising. The line of selection had become early, erect, hardy, dark-green plants, bearing many big pods with two or three seeds per pod. In addition, Badami has more recently made many crosses involving a number of strains. In the last available report (4), he states that several thousand progenies of these crosses are under observation.

McNess (9) reports briefly upon an experiment in selecting the progenies of single plants. Five hundred and eleven plants of white Spanish peanuts entered the test. Their progenies were compared from 1918 to 1922 when only 16 of the original strains remained. The strain finally chosen for increase contains 49.18% oil in the seed compared with about 44% in the commercial Spanish peanut. This strain averaged in 1927 about 18% heavier nuts and 23.68% greater yield than the common Spanish peanut.

THE PEANUT PLANT

Botanists have described 12 species of the genus *Arachis*. All are found in South America, most of them in Brazil. Only the common species, *A. hypogaea*, is found elsewhere. It is generally believed to have originated in South America. *A. nambyquarae* is cultivated by the Nambyquaras Indians of Western Brazil (7), while *A. Rastiero* is grown as a green manure crop in Southern Brazil (6). Presumably, the other nine species exist only in the wild state. Seven of them are perennial. In some respects the collection of wild types of *Arachis* from South America for possible use in breeding experiments would seem a worthwhile project.

The common peanut plant, *A. hypogaea*, may be described as a low annual leguminous plant. The central stem is upright The numerous branches vary from fully prostrate to nearly erect. The central stem is usually taller in the more erect varieties. Varieties are fairly well separated into the bunch and runner types. The Virginia Bunch, however, is semi-prostrate.

Waldron (13) divides the species into two subspecies, *viz.*, *fastigiata* for the bunch type and *procumbens* for the prostrate type. He postulates separate origins of the two types as follows, "Now the wild Brazilian species, *A. pusilla*, is an erect plant, simulating the bunch variety and is reported as growing in dry woods and shady places. Another, *A. prostrata*, is more trailing and grows in open sandy places and so, simulating the prostrate cultivated variety, is more xerophytic. *Thus the possibility is suggested, first that the cultivated bunch varieties are derived from such a species as A. pusilla and second that the prostrate varieties are derived from A. prostrata.*" It may be noted that the two types have been frequently crossed and have produced hybrids which give no evidence of sterility or any other abnormality, which might indicate a species hybrid.

In the subspecies *fastigiata*, Waldron (13) places the varieties White Spanish, Red Spanish, Valencia, and Tennessee Red. Tennessee White should also be included. These varieties are sometimes spoken of as the "Spanish type". Under the subspecies *procumbens*, Waldron places the variety known commercially as Georgia Runner (other names being North Carolina Runner, Florida Runner, Alabama Runner, African, Wilmington, etc.) and the Virginia varieties Jumbo, Virginia Runner, and Virginia Bunch. Virginia Bunch is a semi-prostrate type appearing identical in other respects with Virginia Runner. These varieties may be spoken of collectively as the "runner type".[5]

When a plant of erect type is pulled the nuts are found closely clustered about the base of the plant. This facilitates harvesting. The prostrate branches of the runner varieties are usually longer than the branches of the erect varieties. When a runner plant is pulled the nuts are found scattered along the branches from base to tip. White Spanish peanuts are an erect variety. They are grown in Florida in solid plantings to be harvested and sold as nuts. Florida Runner peanuts are usually interplanted with corn to be hogged off. No other variety is of much importance commercially in Florida. Spanish peanuts have a higher oil content in the meats, the hull is thin compared with the hulls of runner peanuts, and the kernels more completely fill the hulls. The result is that Spanish peanuts produce more oil per ton of unshelled nuts and are therefore preferred by the oil mills.

The Spanish types will sprout very soon after maturity if the soil is warm and moist. A rainy period at harvest time may produce considerable damage. The Virginia and African types may be left in the ground for sometime after maturity without danger of sprouting. Fields of Florida Runner peanuts are often left in the ground until late in the winter before being hogged off. No damage from sprouting results. This is in part due to the fact that runner types do not mature so early as the Spanish. Comparative tests show, however, that with shelled seed planted just after maturity and kept near optimum germination conditions the Spanish will emerge in about seven days, while the runner types will lie dormant for three months or more before germinating. The hull of the runner peanuts is considerably thicker and heavier than the hull of the Spanish which may cause a further difference in time of germination of unshelled seed.

Peanut flowers are borne in the leaf axils, either above or below the ground. The belief still persists, to some extent, that the peanut plant produces two kinds of flowers. Botanists, however, have for some time been agreed that the flowers are of one kind and complete.

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[5] See A. Chevalier (6) for a more complete discussion of varieties.

The ovary is sessile. The calyx consists of a long slender tube crowned with five calyx tips. The corolla is typically papilionaceous borne at the end of the calyx tube. The calyx tube thus appears as a flower stalk. Anthers are of two kinds, *viz.*, two-celled and one-celled, borne alternately. There are 10 stamens, but all of them may not be fully developed. The style is very long and slender, and is terminated by a stigmatic surface at the tip. In mature flowers the stigma usually lies buried among the dehisced anthers in the tightly closed keel petal. Self-fertilization is thus assured, except for the visitations of insects. Insects, other than thrips, very rarely visit peanut blossoms.

The fruit is an indehiscent legume containing one to six seeds. The Valencia, Tennessee Red, and Tennessee White varieties commonly produce one to four seeds per nut. Other varieties common in this country rarely produce more than two seeds per nut. The fruit forms only under ground. The ovary stalk, gynophore, or peg is positively geotropic. It grows downward into the soil bearing the ovary and fertilized eggs near the tip. Growth of the ovary into a fruit does not commence until it is buried in the soil. Pegs have been observed to reach the soil and produce seed from a height of 14 inches above ground. If a portion of a branch is covered with soil, flowers may bloom and fruit form without any appearance above the surface. The underground portion of the peg and the pod are covered with hairs which are presumably absorptive in function. Waldron (13), Reed (11), and other workers report root-hairs scanty or absent on the peanut plant.

The seed is a straight embryo, covered with a thin papery seed coat. The outer layer or testa varies in color from brick-red in the Valencia, Tennessee Red, and Red Spanish to russet in the Virginia and African types and to light tan in the White Spanish and Tennessee White varieties. Seeds of the Valencia, Tennessee Red, and some other varieties often exhibit a purple area of varying size and intensity on the surface. This character was noted by Koch as cited by Fruwirth (8). He was unable to account for its erratic appearance or non-appearance in succeeding generations. The plants of these varieties develop considerably more of the purplish pigments in various parts of the plant than do other varieties. The development of this pigment seems to depend upon sunlight. We have examined fruits of these varieties which had become partially uncovered during development and had developed some chlorophyll in the pod. The seed invariably were spotted with purple. Other fruits on the same plants, well covered with soil, did not show any purple pigment on the seed.

Arachis nambyquarae was described as a new species in 1922, and soon thereafter was introduced into this country. It is not grown commercially. The plant does not differ markedly from *A. hypogaea* in general appearance. It is described by Hoehne (7). The pods are large and typically two-seeded. The seeds also are large equalling or exceeding the largest Jumbos. The seeds are bi-colored or variegated red and white. This variegated appearance is due to the testa or outer layer of the seed coat failing to grow apace with the embryo. The testa is red in color. The tegmen or inner layer of the seed coat is papery white. When the seed is mature the testa lies in irregular patches over the surface. The seed therefore appears papery white splotched with red. The plants are very slow growing and have not made good yields at Gainesville. Hoehne was uncertain whether the plant is perennial or annual. He states that the plant continues to grow after the maturation of fruit. In this respect it does not differ from *A. hypogaea*. Both plants appear indeterminate in growth in a satisfactory environment which would include reasonable freedom from insects and disease.

Characters of *A. nambyquarae* which may be useful to the breeder are large seed, high oil content, distinctive flavor, and the reduction of the testa. The possibility should not be overlooked of practically eliminating the testa by hybridization of *A. hypogaea* with *A. nambyquarae*. The thin white tegmen or inner seed coat remaining might not prove so objectionable and in some manufacturing processes it might be possible to dispense with the blanching and reduce the percentage of "splits". Hoehne described the seed as "two colored (white and purple to single colored, white yellow to purplish)".[6] The white seeds no doubt were extreme reductions of the testa. Whether such variations are heritable or fortuitous cannot be stated at present. In our stocks the seeds are commonly covered with the reddish testa over approximately 50% of the surface. It may be further noted that very light variegation occasionally occurs on seeds of *A. hypogaea*.

PLANT-TO-ROW SELECTION EXPERIMENTS WITH SPANISH PEANUTS

Seventeen lots of seed from different parts of the Spanish peanut belt were planted at Gainesville in 1920. Ten of these lots were selected and 10 superior plants were chosen from each lot. These 100 plants furnished the seed for a plant-to-row test in 1921. Twenty strains were selected from this test on the basis of yield of sound nuts.

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[6] Thanks are due Dr. M. N. Walker for the translation of Hoehne's paper.

Each strain represented the progeny of an original plant. These 20 strains were tested during the following four seasons, 1922-25. An unselected lot of Florida Spanish peanuts was used throughout these tests as a check. Seven of the selections were tested four additional seasons (1926-29) with the same lot of Florida Spanish peanuts as a check. In Table 1 are shown the eight-year average yields of nuts and the two-year average yields of vines and roots. The percentages of fat, protein, and nitrogen-free extract, shelling percentage and the mean weight of seed for the 1922 crop have also been included.

Table 1.—*Observations on seven selected strains of Spanish peanuts and one unselected strain of Florida Spanish peanuts grown at Gainesville, Fla.*

			Dry basis*			Air dry*	
Strain No.	Pounds of nuts per acre, 8-year ave.	Pounds of vines and roots per acre, 2-year ave.	Fat %	Protein %	Nitrogen-free extract %	Shelling %	Mean weight of seed, grams
4427	961	1,152	45.0	28.8	15.8	80.7	0.99
172411	875	1,225	44.7	28.8	16.1	77.3	0.88
16233	958	1,511	44.6	29.4	16.6	78.3	0.83
44217	1,009	1,535	43.1	28.1	16.1	75.7	0.72
153118	862	1,453	44.1	27.2	17.5	78.3	0.85
14183	878	1,260	44.2	27.9	16.1	74.2	0.83
61611	882	1,477	44.7	28.1	15.2	74.8	0.77
Fla. Spanish	747	1,408	45.2	29.7	15.9	77.2	0.75

*Grown at Gainesville in 1922.

Unfortunately, yield records are not available on the original lots from which the selections were taken. There is no reason to believe, however, that the check strain is not a fair representative of farm-run Spanish peanuts. This strain has also been included in the peanut variety test at Gainesville for five seasons along with an improved strain of Spanish peanuts. This improved strain was secured from the Pee Dee Experiment Station at Florence, South Carolina. The results of the variety test are summarized in Table 2. The fact that the Florida check strain yielded higher than the improved strain is further evidence that it is of fair yielding ability. All of the selected strains show an increase in yield over the unselected check strain. The average gain of the selections over the check strain for the eight-year average yield of nuts amounts to 22.8%. The gain of the highest yielding selection amounts to 35.0%. Prolonged rainy weather at harvest time in the season of 1928 resulted in almost a total loss of seed of the selections. This was due to the fact that Spanish peanuts sprout very soon after maturity if the soil is damp and warm. The crop of 1929 was therefore very small. It was also badly weather damaged because the shocks were so small. As a consequence, the determinations of shelling percentage, seed weight, and the chemical analyses have been deferred until a supply of sound seed is available. All of the available seed of these selections was planted in 1930 for increase and for a yield test with other lots of Spanish peanuts. From the data now available it appears very probable that some of these selections are markedly superior in yield of nuts to the farm-run of Spanish peanuts. Since selection was based entirely upon the yield of sound nuts, the effect of selection upon other characters cannot be considered except as they may be correlated with yield.

TABLE 2.—*Summary of peanut variety tests, Gainesville, Florida, 1923–26 and 1928.*

Variety	Pounds of nuts per acre, 5-year ave	Fat* %	Protein* %	Nitrogen-free extract* %	Shelling* %	Mean weight of seed, grams*
Spanish (Fla.)	654	45.2	29.7	15.9	77.2	0.75
Spanish (Imp.).	598	46.6	31.9	12.2	73.2	1.08
Valencia	572	43.0	33.1	14.1	67.5	0.96
Va. Bunch .	962	47.5	27.5	11.2	70.6	1.18
Jumbo Runner.	943	44.9	27.5	18.7	57.8	1.38
Fla. Runner.	1,021	—	—	—	—	—

*Grown at Gainesville in 1922.

The plant-to-row test of 1921 consisted of a single progeny row from each of the selected plants. Since stands were not good, due to the small amount of seed, yields were based upon the yield of 20 plants from each row. These 20 plants were taken at random, except that care was used to select only those plants which were surrounded by a full stand in the same row and in the adjacent rows. From the 20 plants for each respective row the total weight of nuts, the weight of sound nuts, and the weight of roots and vines were recorded. From these data the following correlations were calculated:

Weight of sound nuts, weight of vines and roots, r = — 0 21
Weight of sound nuts, percentage of sound nuts r = + 0.72
Weight of vines and roots, percentage of sound nuts r = — 0.43

These correlations are based upon 94 plant rows. The data for each plant row are based upon the average of 20 single plants. Based on Fisher's[7] Table 5, A ("Values of the Correlation Coefficient for Different Levels of Significance"), the value of "P" for the first correlation coefficient is somewhat less than 0.05. The other two correlations are highly significant. The first correlation indicates that there is some tendency for greater yield of sound nuts to be associated with smaller yield of vines and roots However, of the seven strains which were retained and which are included in Table 1, the one with the highest yield of nuts also has the highest yield of vines and roots. The second highest yield of nuts was made with the lowest yield of vines and roots, while the third highest yield of nuts was made with the second highest yield of vines and roots. Taken together these results seem to indicate that there is no marked relation between yield of sound nuts and yield of vines and roots. The high positive correlation between weight of sound nuts and percentage of sound nuts would be expected, for in this test the unsoundness arose principally from failure to fill. The unsound nuts were those which did not fill, commonly called "pops". The rather high negative correlation between yield of vines and roots and percentage of sound nuts might be plausibly explained on the assumption that the larger vined types were too closely planted to produce well filled nuts, while the smaller types were not. This test was planted in 30-inch rows with plants spaced about 6 inches in the rows. This is a common spacing of Spanish peanuts. It is impossible to state, at present, whether this relation is due to greater competition in the larger types or to something inherent in the species. In either case it is important, however, for the shelling percentage is a big factor in determining the grade of peanuts.

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[7] FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 2. 1928.

HYBRIDIZATION EXPERIMENTS

It is generally believed that cross-fertilization occurs very infrequently in common peanuts. No determinations of the amount of natural crossing have come to the writers' attention. However, the flower structure and the general uniformity of varieties and of the progeny of plant selections lend considerable support to this belief. It therefore seemed desirable to make variety crosses to induce variability. Also, it seemed desirable to combine certain characteristics not found in any single existing variety.

As a preliminary experiment, 12 strains, representing the better-known varieties, were intercrossed. This was done with the hope of determining which combinations might be best for further work. The Horticultural Office, Bureau of Plant Industry, U. S. Dept. of Agriculture sent seed of nine strains. To these were added two strains of White Spanish from the selection experiment described above and a local strain of Jumbo Runner. One plant was selected from each of the 12 strains and an attempt was made to intercross these 12 plants. Not all of the crosses were successful, but a goodly number of hybrid seed were produced. After the cross pollinations were made, each parent plant was allowed to set seed from natural pollination. It was assumed that for practical purposes the progeny of any single plant would serve as a pure line for comparison with the hybrids.

A number of hybrid seeds and one seed of each parent strain were planted in the greenhouse 10 days after harvesting. It was not known at this time that the dormancy of seed in the runner type was inherent in the seed. The non-sprouting of the runner type was attributed to the thicker and probably more impervious pod. The seed in this planting were shelled. All of the parent strains of Spanish type emerged on the sixth day. The runner type parent strains emerged later, ranging from the forty-second to the sixty-second day. Crosses between strains of the Spanish type emerged on the sixth day also. There were four hybrids between the Spanish and runner types. The pollen parent of each hybrid was the runner type. The emergence of these hybrids ranged from the seventeenth to the forty-eight day, being intermediate between the parents in each case. Since it is impossible to harvest the seed at the same stage of maturity, these figures can only roughly indicate the length of the dormancy period. The remainder of the hybrid seed was planted in a similar comparison with the parent strains five months later. Practically all of this planting emerged on the eighth day. A few of the hybrid seed were small and did not emerge until the ninth day Apparently, the dormancy period had been completed before the second planting was made.

The seed from the F_1 hybrids between Spanish and runner type parents were then harvested as nearly as possible when just mature, and planted 10 days later in clean sand in the greenhouse. The emergence of several such F_2 progenies has extended over a considerable range, from a few days to 11 months. Five seeds from each F_2 plant are also being similarly tested for length of dormancy period. The results now available indicate that the seed dormancy of runner peanuts is inherent in the seed and not the result of an impervious seed coat. The character is incompletely dominant to the non-dormancy of the Spanish type peanuts.

In the comparisons of F_1 hybrids with the parent strains notes were taken on the size of the plants, on the blooming, and on the setting of seed. These results for the first test were rendered worthless by a severe attack of bud worms when the plants were about 6 weeks old. These plants however lived for 8 or 9 months, producing three main crops of seed. In so far as was possible the seed were harvested when mature. However, some seed were taken when immature and others when past maturity due to the impossibility of determining the stage of maturity without cracking the pod. Yield records were therefore worthless for comparison.

There were 25 F_1 plants in the second planting. Only one plant of each parent strain could be included due to lack of space in the greenhouse. Three of the crosses were between Spanish and runner types. The other crosses were between Spanish types. Since there was no apparent difference between the Spanish-runner crosses and the Spanish crosses, the data have been summarized together. In no case was the gain of a hybrid over the greater parent very great. Nor did the hybrids either individually or as a lot appear more vigorous than the parent strains. The 25 F_1 plants represent 11 different crosses between 10 parent strains. A summary of the data on characters which in this test seemed the best indications of comparative vigor is given in Table 3. The figures indicate how many of the 25 hybrids exceeded their greater parent, the average of parents, and the lesser parent for the respective characters. In the second column of the table is given the number of the hybrids which exceeded the greater parent for each of the respective characters. If the hybrids had each equaled the greater parent in inherent vigor, the values expected in this column would have been 12.5 on the basis of random sampling. Since this value was exceeded in only one case and then only slightly, the conclusion must be that the hybrids did not exceed their greater parents for the characters listed. These data are not very extensive, yet they serve to indicate that no great amount of hybrid vigor may be expected in crosses between different varieties of peanuts.

TABLE 3.—*Comparison of 10 parent strains and of 11 F_1 crosses of peanuts.*

	Number of the 25 F_1 plants which exceeded the		
Characters studied	Greater parent	Average of parents	Lesser parent
Height 64 days after planting	0	6	10
Spread 64 days after planting	4	7	8
Number of leaves 64 days after planting	10	12	14
Total blossoms 64 days after planting	12	15	17
Total blossoms 100 days after planting	15	20	21
Total pegs 57 days after planting	4	8	18

Inheritance studies will usually be of more value to the science of genetics if conducted with those species the analysis of which is much further along. However, some inheritance studies should be conducted with peanuts, for Waldron (13) has postulated that the erect and runner types have arisen separately from two different wild species. Also, no information is now available upon the number or the behavior of the chromosomes of *Arachis*. There are few definite character differences in the peanut plant to serve as a basis for inheritance studies. This is largely due, no doubt, to the species being very closely self-fertilized.

Seed coat color is the only character which could be definitely classified in our cultures. Most of the plants were grown in the greenhouse at various times throughout the year. This has made it impossible to classify definitely on the basis of habit of growth, number of seeds per pod, foliage color, or development of anthocyanin pigment in the plant parts. The color of the seed coat is of three shades, *viz.*, brick red, russet, and tan. Brick red may be easily separated from the other two colors. Russet and tan cannot be definitely classified if grown in the greenhouse. Brick red has appeared fully dominant in every cross in which it was involved. The color is found in the testa, which is mother tissue, and therefore no xenia nor variation in color of the seeds of a single plant is expected. Four crosses involving brick red and tan color of seed coat have been carried through the second generation. All of the parents were of the erect type. Since these crosses have been discarded from the breeding experiment, the F_2 data are presented here without F_3 confirmation. The data are presented in Table 4. Agreement with the theoretical ratio (3:1) is close in every case. This tends to confirm the reports of Van der Stok and Badami as noted above. Later crosses now in the first generation involve color of seed coat, habit of growth, number of seed per pod, seed size, and seed dormancy.

TABLE 4.—*Summary of F_2 progenies of crosses involving red and tan color of seed coat.*

Ped. No.		Red	Tan	Total	P
3 x 7	O.	20	6	26	0.80—
	C.	19.5	6.5		
4 x 2	O.	32	8	40	0.53
	C.	30	10		
6 x 4	O.	13	5	18	0.79
	C.	13.5	4.5		
12 x 7	O.	18	8	26	0.50
	C.	19.5	6.5		
Total	O.	83	27	110	0.90
	C.	82.5	27.5		

Seed dormancy is usually considered essential in a satisfactory "hogging off" variety. It would also seem desirable in varieties for market growing, especially in sections where frequent rains occur during the harvesting period. United States grades for peanuts of various classes define all kernels with sprouts more than one-eighth inch long as damaged. Three per cent of damaged kernels is the maximum tolerance in No. 1 peanuts. The difference in price paid the farmer for No. 1's and No. 2's frequently amounts to 20%. It would seem then that seed dormancy might in many cases play an important part in determining the grade and the value of a crop. Erect or bunch varieties are more easily harvested than the runner types. Light tan color of seed coat is probably more desirable in a market variety. Selections of plants combining erect type, light tan seed coat, seed dormancy, and good general appearance have been made in the second and third hybrid generations. The progeny of these plants will be increased until the sixth or seventh generation, when a considerable degree of homozygosity should be attained, before further selections are made.

SPECIES CROSSING

The cross *Arachis hypogaea* x *A. nambyquarae* has been successfully made with both Spanish and runner-type varieties of *A. hypogaea*. The reciprocal cross has failed in the few attempts which have been made. *A. nambyquarae* produces few flowers and is extremely slow growing under Florida conditions. Six hybrid seed representing crosses of four Spanish strains and two runner strains of *A. hypogaea*. with *A. nambyquarae* were planted 10 days after harvest. The four of Spanish parentage emerged between the twenty-eighth and fortieth days after planting. The other two which were of runner parentage were examined 260 days after planting and appeared to be in sound condition. One of them emerged 332 days after planting. The other seed at that time was partially decayed and apparently dead.

The four hybrids of Spanish type *A. hypogaea* x *A. nambyquarae* have produced seed and appear to be fully fertile. They are in general intermediate between the parent species and in the greenhouse have given no evidence of hybrid vigor. The seed pods and seed produced by these F_1 plants possess obvious *A. nambyquarae* characters. The red color of the testa in *A. nambyquarae* appears completely dominant to the light tan color of the testa in *A. hypogaea*. Variegation or rupture of the testa in *A. nambyquarae* was incompletely dominant to self color or no rupture of the seed coat as in the *A. hypogaea* parents.

SPECIAL TECHNIC

Preliminary observations at this Station on the flowering habit of peanuts established the following pertinent facts. In normal environment flower production is very regular. A crop of blossoms is produced every 24 hours. The flowers of each day are usually very nearly at the same stage of development. The buds appear above the leaf axils during an afternoon. The calyx tube continues to elongate, the flower unfolds, and the anthers ripen during the night.

Before dawn the flower is fully open, the anthers have dehisced, and the flower withers during the same day. Fertilization apparently has no effect in hastening the withering of the flower. In general, the best time for emasculation is during the 30 minutes preceding the stage when the anthers will burst if grasped by forceps. At this time the calyx tube will have reached about one-half of its full length. Between 10:00 and 11:00 p.m. emasculation has been quite successful. Since the pollen is somewhat oily and therefore tends to adhere, there is small danger of it blowing about in a greenhouse. No insects other than flower thrips have been observed visiting peanut blossoms. The flower thrips are numerous and undoubtedly carry pollen on their bodies. However, a number of emasculated flowers have been left from time to time with one-half of the petals torn away and the stigma fully exposed. None of these have given any evidence of fertilization. Of the 60 or more F_1 plants from hand pollination, only one has given evidence of being other than what was supposed. This one was very probably the result of self-pollination. No attempt has been made to protect the emasculated flowers.

Pollinations have been made when convenient between 8:00 and 10 a.m. of the morning following emasculation. Approximately 50% have been successful. Possibly a greater success might be attained if the pollinations were made earlier in the morning. Since the flowers wither so quickly and the gynophore or peg does not appear until a few days after fertilization, it is necessary to invent some means of attaching a label. We have used small wire wickets stuck in the soil to carry the labels. A small thread runs from each label to the flower. The thread must be small for the withered blossoms are very easily detached from the end of the peg. When the peg has reached a length of about 0.5 cm, the flower should be pulled off and the thread attached to the peg. The pegs will not develop if fertilization is not accomplished.

It has been found convenient to grow the plants for hand pollination in 4-gallon stone jars. These may be moved about to suit the convenience of the operator. It seems desirable to keep the plants pruned back, to pluck off each morning the flowers which have not been used, and to prune off all pegs except those of the desired crosses. It is best to use for the pistillate parent a vigorous plant which is blooming freely and upon which there are few or no pegs. A number of developing fruits on a plant may inhibit blooming or they may inhibit the development of the peg after fertilization. This latter point has been proved by removal of all pegs on certain plants which had not bloomed for some time and the subsequent development of new pegs without intervening blossoms. Peanut plants will bloom until a set of fruits is accomplished. When these fruits are well along blooming will be resumed. Blooming may be induced at any time by removing the developing fruits which are drawing up on a plant. After a dozen or so crosses have become well started the pruning of pegs may be discontinued and the plant will produce plenty of seed by natural self-pollination to maintain the parent line.

Since self-fertilization is so nearly complete in peanuts no special precautions are necessary to prevent accidental mixtures by crossing in the field. It is necessary, however, to place the breeding plat on land which has not grown peanuts the previous season, for the dormant types overwinter easily and volunteer in the spring. Also, seed of the non-dormant or Spanish types may lie through the winter on the surface of the ground or in dry soil and be in good condition to appear with the next crop.

SUMMARY AND CONCLUSIONS

Plant-row selections of Spanish peanuts made on the basis of yield of sound nuts have produced definitely higher yielding strains at Gainesville.

Emasculation of peanut blossoms may be successfully performed when the calyx tubes have reached approximately one-half of their mature length. Usually under satisfactory conditions, the blossoms are in this stage between 9:00 and 11:00 p. m. Hand pollinations are successful if performed in the morning following emasculation.

The production of improved varieties combining such characters as seed dormancy, erect type, large seed, dark green foliage, light tan seed coat, and high or low oil appears possible by hybridization and selection. Since no existing variety has all of these desirable characters, it will probably not be possible to produce the best improved varieties by plant selection without hybridization.

Seed dormancy as found in runner-type peanuts, contrasted to non-dormancy as found in Spanish-type peanuts, is an inherent property of the seed. It does not depend upon an impervious or protective seed coat. Dormancy is incompletely dominant to non-dormancy.

A comparison of certain characters indicative of vigor in 11 different crosses and in the parent strains did not show any excess vigor in the first generation hybrids.

The color of the seed coat in common peanuts varies from brick red as in Valencia to russet as in the runner types and to light tan as in White Spanish. Brick red has behaved as a unifactoral dominant to light tan in inheritance tests.

The cross *Arachis hypogaea* x *A. nambyquarae* is reported. The F_1 hybrids are in general intermediate to the parent species and appear to be fully fertile. Red color of the testa in *A. nambyquarae* is dominant to russet and light tan in *A. hypogaea.* Variegation in the seed coat, as found in *A. nambyquarae*, is incompletely dominant to self-color, as found in *A. hypogaea.*

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A SUCCESSFUL TRANSFER OF EMMER CHARACTERS TO *VULGARE* WHEAT[1]

EDGAR S. MCFADDEN[2]

The principal factors that reduce the yield and lower the quality of wheat during its growing period in the northern spring wheat area of the United States are drought, extreme heat, high winds, frost, hail, insect pests, and fungous diseases. It is safe to say that no crop of wheat is ever produced anywhere in this area without the yield or quality of the grain being materially influenced by one or more of these limiting factors. The development of varieties of wheat that are resistant to these destructive agencies, therefore, is of great economic importance.

Yaroslav emmer, a variety of *Triticum dicoccum*, grown to some extent as a feed crop in the northern spring wheat area under the trade name of "speltz," possesses considerable resistance to several of the destructive agencies mentioned above. It has a tough, flexible straw and a heavy, tight-fitting chaff, which characteristics give it considerable resistance to breaking down of the straw and shattering of the seed by wind and hail. It is practically immune to stem rust, *Puccinia graminis*, and very resistant to orange leaf rust, *P. triticena*, and probably also to loose smut, *Ustilago tritici*. Yaroslav emmer also has several other characters that would be of value in common wheats, such as a high capacity for tillering when grown under favorable conditions and an exceptionally high protein content. On the other hand, considered from the standpoint of a commercial bread wheat, this variety of emmer has many decidedly undesirable characteristics. Among the more outstanding of these are a fragile rachis, a poor type of kernel, a long heavy brush, an extremely soft gluten, as well as susceptibility to several diseases to which many of the bread wheats possess some resistance. Among these diseases are black chaff, anthracnose, and a form of root rot that causes firing of the plants just before ripening.

Emmer (*T. dicoccum*) and the common wheats (*T. vulgare*) belong to distinct species differing in chromosome numbers. Emmer has 28 somatic chromosomes, while the common wheats have 42. For this reason, the problem of uniting the desirable characteristics of the two by cross breeding is somewhat complicated. As reported by several investigators, the principal difficulties connected with the cross breeding of wheats belonging to different chromosome groups are the occurrence of more or less sterility in the F_1 and following generations and linkage of characters. In numerous crosses made by the writer between common wheats and rust-resistant varieties of durum wheat, which also belongs to the 28-chromosome group, resistance to stem rust has been found to be closely linked with certain spike and kernel characters of the durum parent. Many other investigators have reported similar results. Since common wheat differs in more respects from emmer than from durum, the chance of obtaining desirable segregates from a cross between common wheat and emmer would naturally appear very remote, if not impossible

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the South Dakota Agricultural Experiment Station, Redfield, S. Dak. Received for publication July 9, 1930.

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CROSSING EXPERIMENTS

The problem of transferring the desirable characters of Yaroslav emmer to the common wheats of the Hard Red Spring class was undertaken by the writer in 1916 when crosses were made between Yaroslav emmer and several varieties of Hard Red Spring wheat. This was undertaken in part as a practical breeding project and in part to test the soundness of a theory held by the writer that modern cultivated forms of wheat originated from inter-crossing between certain wild wheat-like grasses, such as wild rye (*Secale montanum*), wild emmer (*Triticum dicoccoides*), wild einkorn (*T. monococcum*), and some one or more of the various species of *Aegilops* Some evidence in support of this theory was obtained from the Yaroslav x Marquis cross, but the details are reserved for later publication

The cross with Marquis will be the only one discussed in this paper This cross was made with a pure line strain of Marquis as the pollen parent and a pure line strain of Yaroslav emmer as the seed parent. The strain of Marquis used differed from unselected Marquis in having a shorter and somewhat broader type of kernel, and in being shorter in the straw and a few days earlier in maturity The strain of Yaroslav used did not differ in general appearance from its unselected parent. However, it was descended from a rust-free plant which was selected in 1915 from a plat of Yaroslav in which most of the plants carried at least a trace of both stem and leaf rust. This strain may actually have been somewhat more resistant to both rusts than the parent variety, but since the seed was lost shortly after the cross was made this point must be left to speculation.

Only a few poorly developed seeds resulted from the pollination of the flowers of several heads of the emmer parent with the Marquis pollen. Upon being planted the following year, only one of these seeds grew. This developed into a vigorous plant with many sturdy culms. The spikes were nearly awnless, quite compact and laterally compressed, while the glumes were distinctly keeled clear to the base, as in the emmer parent. In fact, with the exception of the lack of awns, the plant closely resembled the emmer parent. The plant displayed considerable resistance to both stem rust and leaf rust, however a few large pustules of stem rust surrounded by purplish areas developed just above the nodes. Some of the spikes failed entirely to develop seed. This failure to produce seed appeared to be due partly to infection by such diseases as black chaff, anthracnose, scab, and ergot, but was principally due to sterility of the florets. None of the spikelets developed more than two seeds, the inner florets of the spikelets being infertile like those of the emmer parent. Many of the outer florets of the spikelets were also infertile, while others developed ergot. The seed produced was exceptionally large while in the dough stage, but upon maturing became badly shriveled and distorted as a result of uneven shrinkage of the endosperm. Something over 100 seeds were produced.

About 100 F_2 plants were grown in 1918 on the Highmore substation at Highmore, South Dakota, from seed of the F_1 Yaroslav x Marquis plant. These plants were of a great variety of forms. Many of them were entirely sterile, while many others succumbed to disease of one kind or another before reaching the fruiting stage. Taken as a whole, the plants of this generation were the most unpromising lot of hybrids that ever came under the writer's observation. A few plants were found that had the appearance of being true *vulgare* wheats, but all of these possessed some outstanding fault. All of the *vulgare* types developed considerable stem rust, although most of the emmer-like plants were practically free from stem rust.

A careful study of the F_2 plants convinced the writer of the practical impossibility of ever being able to separate desirable segregates from the progeny of this cross by ordinary methods of systematic selection. It was, therefore, decided to grow the material *en masse* for several generations so as to allow natural selection to eliminate some of the weaker and undesirable combinations while, at the same time, allowing further opportunity for the appearance of more desirable segregates carrying their characters in a homozygous condition. Accordingly, all of the F_2 plants were harvested and threshed together.

A large F_3 generation was grown at Highmore in 1919. This generation, in the main, was nearly as unpromising as the F_2 had been.

Consequently, the plants of the F_3 were harvested and threshed together as in the case of the F_2. Since stem rust and several other diseases were exceptionally destructive in 1919, most of the plants that did not possess a high degree of resistance to the various diseases produced badly shrunken grain This gave an excellent opportunity to make a rather sharp separation of the resistant types from the susceptible types by mechanical means which was accomplished as follows: The mixed hybrid plants were first threshed together with a small nursery thresher having the cylinder speed reduced considerably so as to prevent separation of the seed from the hull in the emmer types. The threshed grain was next run through a Clipper seed cleaner, using an upper screen of the proper mesh to run off most of the seeds to which the hull had adhered in threshing. A rather coarse rectangular mesh screen was used beneath to separate the plump seed from the naturally slender types and seed that had been shrunken as a result of disease injury. A strong air blast was used to blow out practically all of the light weight seed that the grading process had failed to remove. The resulting plump, heavy seed which represented, in large measure, the disease-resistant types was next run through an Emerson kicker which removed the long-kerneled types and left only the short, plump types. After the seed had passed through the various mechanical elimination processes described, only a fraction of 1% by bulk of the original seed remained.

Between 4,000 and 5,000 F_4 plants were grown at Highmore in 1920 from the mechanically selected seed of the F_3 generation. These F_4 plants were carefully observed during the growing season, and about 100 of the more promising ones tagged for selection and further study. Due largely to uneven shrinkage of the endosperm, these selections were later all discarded with the exception of six which appeared to be true common wheats possessing all of the desired characters of the emmer parent. All of these selections were free, or nearly so, from all recognizable diseases. Both awned and awnless types were represented.

On June 30, 1920, cooperative relations between the U. S. Dept. of Agriculture and the South Dakota Experiment Stations were discontinued, and as a result cereal breeding projects conducted thereunder likewise were discontinued. After harvest of the 1920 crop the writer moved to his farm near Webster, S. Dak., by arrangement taking seed of the six selections from the Yaroslav x Marquis cross along for further observation.

In the spring of 1921, the six Yaroslav x Marquis selections were planted in progeny rows on rich garden soil at Webster, S. Dak. This was an extremely dry year, as a result of which several of the selections failed to produce grain. This was also true of the check rows of Marquis. Kota wheat, which was also used as a check, fared only a little better than the Marquis. Two or three of the selections having narrow leaves of a peculiar blue green color, similar to those of the Yaroslav parent, proved to be very resistant to drought, and as a result, developed considerable grain of good quality.

Plant diseases were not at all prevalent in 1921, although Marquis developed considerable stem rust late in the season, while Kota developed considerable leaf rust. Nevertheless, all of the Yaroslav x Marquis selections remained entirely free from stem rust, and developed only a trace of leaf rust. The more promising of these selections were reselected for kernel type and these new selections were grown in progeny rows in 1922.

Very little disease of any kind developed in the nursery in 1922, so no data on disease resistance of the selections were obtained. The nursery was struck by a severe hail storm on July 15 which practically destroyed the check rows of Marquis and Kota. Following this storm, it was noted that several of the Yaroslav x Marquis selections had received very little injury as a result of their heavy chaff and wiry straw. Since none of the selections were entirely homozygous for all characters, new selections were made from the rows that showed the greatest resistance to hail injury.

The plant selections made in 1922 were grown in progeny rows in 1923 in comparison with Marquis and several other standard varieties. Although none of the Yaroslav x Marquis strains had ever developed so much as a trace of stem rust since the first selections were made in 1920, it was not until 1923 that they were subjected to a severe test for rust resistance. A severe epidemic of stem rust developed early in July of this year, and these selections remained entirely free from all traces of the disease, whereas check rows of Marquis and other susceptible varieties developed a 100% infection.

In addition to stem rust, several other diseases were very prevalent in the nursery in 1923. During this year, it was first discovered that the Yaroslav x Marquis selections had inherited the peculiar susceptibility of the Yaroslav parent to black chaff, anthracnose, and a form of root rot. After making this discovery, an attempt was made to find individual plants that carried resistance to these diseases. Sixty-three plants that were practically free from infection by these diseases were selected for testing in 1924.

In 1924, the 63 plants selected the previous year were grown in progeny rows and carefully observed to determine their reaction to black chaff, anthracnose, and root rot. None of the selections proved to be very resistant to any of these diseases. However, a few of them gave indications of being slightly more resistant to black chaff and root rot than the general run. About 20 of the more promising strains were harvested and threshed. Samples of seed of each of these were sent to the late Professor A. L. Bushey of the South Dakota State College who analyzed them for protein content. The results of these analyses showed a wide range in protein content between the different selections, running from less than 12% to more than 17%.

Following this test, about half of the selections consisting of the low protein types were discarded. Some simple chewing tests were made by the writer to determine the quality of the gluten in the remaining selections. By means of these tests, considerable variation in the nature of the gluten was detected in the different selections. Some of them proved to have a rather soft, or loose, type of gluten similar to the emmer parent, while in others, the gluten was of an extremely tight nature as in the Marquis parent. Samples of the gluten (gum) from all of the selections were rolled into balls, placed on a pie tin, and baked in a slow oven. The results were very striking. In every case the gluten which had been classed as "loose" in the chewing test produced flattened loaves, while that classed as "tight" produced upright loaves. This experiment was repeated several times with but slight variation in the results. Following these tests, three of the selections that had run especially high in protein and possessed the "tight" type of gluten were saved for further testing, and for use as parents in further breeding work. Among these were two awned strains designated as H44-24 and H49-24, and an awnless strain designated as H35-24.

Numerous protein and gluten tests of these selections have since been run by several different commercial firms, and in every case the protein has been reported as exceptionally high and the gluten as having good strength. Reliable comparisons between the quantity and quality of gluten in these selections and their Marquis parent have not been possible due to the failure of Marquis to produce seed of good quality in the writer's nursery during the last few years. However, the meager data at hand appear to indicate that these selections have inherited the high protein capacity of the emmer parent combined with the good quality of gluten of the Marquis parent. A further study of this point is being made which will be reported on later.

The three selections, H44-24, H49-24, and H35-24, were grown in 5-foot rows in the writer's nursery in 1925 in comparison with standard commercial varieties, Marquis wheat being grown as a check every tenth row. H49-24, which had made the best showing in 1924, also was grown in duplicate 8-rod rows. A severe epidemic of stem rust developed in commercial fields of bread wheat in the vicinity of the writer's nursery early in July of 1925. This epidemic later spread to the nursery where it became extremely severe. In addition to the natural inoculum that came into the nursery from surrounding fields, an attempt had been made to create an artificial epidemic in the nursery which probably had some influence on the severity of the disease. Nine of the most virulent physiologic forms of stem rust known to occur in the Northwest were introduced from the Plant Pathology Department of the University of Minnesota and were used to inoculate border rows of Ruby and Little Club which completely surrounded the nursery.

The following physiologic forms were used: 1, 3, 9, 17, 18, 21, 29, 30, and 36. These, for the most part, are forms that develop normally on the seedling stage of both Kota and Kanred wheats, two varieties of common wheat that show a high degree of resistance to several forms of stem rust. Two of the forms, *viz.*, 9 and 30, are also known to develop normally in the seedling stage on Yaroslav emmer. The border rows of Ruby and Little Club were inoculated with the introduced forms on the evening of June 24, and in addition, pots containing seedling plants heavily rusted with the above forms were introduced into the nursery at the same time. These potted plants were placed between the border rows of Ruby and Little Club near the corners of the nursery.

Immediately following the inoculations and the introduction of the rusted plants into the nursery, there followed two weeks in which dews were extremely heavy. Then came five consecutive days of extreme heat from July 10 to 14. As a natural result of these favorable conditions, stem rust developed rapidly on the border rows of Ruby and Little Club, and soon spread to the susceptible varieties throughout the nursery. By July 15, there was a heavy infection on Marquis which extended up as high as the flag leaf. By July 28 the infection on Marquis extended clear up to the base of the spikes and was recorded as 100%. All other varieties of bread wheat in the nursery, including Kota and Webster, developed a heavy infection. Two Kanred x Marquis selections, which show a high degree of resistance to certain forms of stem rust in the seedling stage, were heavily infected, and appeared to be the most severely injured of any of the varieties. Vernal emmer, a variety practically identical with Yaroslav, also developed rust in the form of a few large linear pustules surrounded by purplish areas located immediately above the upper nodes.

In spite of both the natural epidemic of stem rust and the attempt to create an artificial epidemic by the introduction of several of the most virulent forms of the disease, some of which are capable of attacking both parents, the Yaroslav x Marquis selections remained entirely free from stem rust pustules. The selections were not only free from pustules, but the stems were practically free from the characteristic necrotic flecks that are often found associated with resistance to stem rust in such varieties as Webster, Kota, Acme, and Khapli. What few necrotic areas were found could not positively be identified as the result of infection by stem rust. They appeared rather to be the result of injury by some other cause. The only indication that the stem-rust organism had succeeded in gaining entrance into the host was found in the occurrence near the nodes on a few of the stems of large purplish areas similar to those often found associated with stem rust pustules in the case of Yaroslav and Vernal emmers. But in no case could any of these purplish areas be found in which stem rust pustules had developed as in the case of Vernal emmer grown under similar conditions in the same nursery. In this connection it will be well to state that it is not at all uncommon to find some of the purplish areas on the stems of both Yaroslav and Vernal emmers where no rust is present.

The complete freedom of the Yaroslav x Marquis selections from stem-rust pustules appears to be the result of two distinct types of resistance. One is the late and brief opening of the stomata which largely prevents the entrance of the rust organism as shown by Hart.[3] The other is the inability of the rust organism to reach the exterior of the host and develop a fruiting stage in case it does succeed in gaining entrance into the host.

SEEDLING AND MATURE PLANT REACTIONS TO STEM RUST

A seedling test for reaction to stem rust was conducted with H49-24 in the spring of 1925, Marquis and Webster being used as check varieties. The rust forms 9 and 30 were used. Both of these forms develop normally on seedlings of both Yaroslav emmer and Marquis. In this test, both forms developed quite normally on the extreme tips of the seedling leaves of H49-24 and the Marquis check. In the case of both forms, the first pustules appeared on Marquis on the seventh day after inoculation and on H49-24 on the ninth day after inoculation. The pustules of both forms were very similar on these two varieties. The H49-24 gave no indications of being resistant to either of the forms aside from the fact that both forms were two days later in forming pustules on the H49-24 than on Marquis.

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[3] HART, HELEN. Relation of stomatal behavior to stem-rust resistance in wheat. Jour. Agr. Res., 39:929–948. 1930.

On the Webster variety, the first pustules did not make their appearance until the twelfth day after inoculation. Furthermore, the pustules of both forms on this variety were extremely small and non-coalescent, indicating some resistance.

The two forms 9 and 30 were propagated on seedlings of H49-24 for several generations after which attempts were made to transfer them to the fruiting stems of potted plants of the same selection and check plants of Marquis and Webster. The mature plant reactions of the three varieties to both forms were as follows.

Marquis.—A heavy infection of large, linear pustules developed beginning on the sixth day after inoculation. Apparently the rust met with little or no resistance to either its entrance into the host or its normal development after entering the host.

Webster.—Numerous necrotic flecks made their appearance on the stems of the host beginning about the sixth day after inoculation. A few of these flecks developed into extremely small, nearly circular pustules between the twelfth and fifteenth day after inoculation. The numerous flecks were interpreted as an indication that the rust met with little resistance to its entry into the host. On the other hand, the failure of the flecks to develop into normal pustules would indicate that the rust had met with some form of resistance which prevented normal development after entering the host

H49-24.—There was a complete absence of both flecks and pustules clear up to the time of ripening of the plants. The absence of both flecks and pustules in this test, as in the field test, offers evidence that the rust organism for some reason failed to gain entrance into the host.

In general, the reaction of the potted plants to the physiologic forms 9 and 30 was very similar to that of the same varieties grown under epidemic conditions in the field where an aggregation of physiologic forms were probably at work. The main difference was in the heavier infection of Webster in the field, and in the occurrence of the purplish areas on the stems of the H49-24 in the field.

The apparently normal development of rust forms 9 and 30 on the seedling stage of H49-24, together with the failure of the same forms to develop even so much as flecks on the mature plants of the same selection in either the potted specimens or in the field, offers good evidence that the seedling reaction to stem rust cannot always be depended on as a reliable indication of a variety's mature plant reaction. Apparently, in the case of H49-24, the mature plant reaction to stem rust is entirely independent of the seedling reaction.

RESISTANCE TO TIP BLIGHT

A period of extreme heat between July 10 and 14, 1925, resulted in considerable blighting at the tips of the spikes in most varieties in the nursery. This was especially true of the awnless varieties. Marquis wheat, which is practically awnless, was quite severely injured in this respect, the spikes being blighted over half way down from the tips. The awnless Yaroslav x Marquis selection, H35-24, showed some blighting at the tip, but not nearly so much as the Marquis parent. The awned selections H44-24 and H49-24 showed very slight injury in this respect.

SELECTION H49-24 NAMED "HOPE"

In the 1925 tests the selection H49-24 proved to be the highest yielding of the Yaroslav x Marquis selections. This selection has a smoother type of kernel throughout than the other selections, the crease especially being less wrinkled. The surface of the kernel in this selection also is less likely to develop flattened areas due to uneven shrinkage of the endosperm. Since uneven shrinkage of the endosperm is an undesirable character that appears to be somewhat linked with rust resistance, the use of H49-24 as a parent in preference to the other selections became quite obvious. Because of its apparent advantages H49-24 was given the name "Hope" and was distributed in the spring of 1926 to experiment stations for use as a parent.

Observations on the reaction of Hope wheat to stem rust have since been made in uniform rust nurseries at something over 50 experiment stations in the United States and Canada. In but few cases has it been reported as developing more than a trace of stem rust, while in most cases it has been reported as entirely rust free, while susceptible varieties under comparable conditions have carried up to 100% of infection.

HIGH TILLERING CAPACITY

Numerous observations on the tillering capacity of Hope and H44-24 wheats show them to have inherited a tendency toward prolific tillering from the Yaroslav parent. Tillering is influenced greatly by the moisture conditions during the tillering stage of the plants. When moisture is abundant during this stage, a great many culms are produced, but, when the moisture supply is low, tillering is greatly inhibited. For this reason, the yields of the Yaroslav x Marquis selections appear to be closely associated with the supply of soil moisture during the early stages of growth. In 1925 and 1927, when moisture was uncommonly abundant in the writer's nursery during May and early June, these selections showed remarkable tillering capacity, and their yields were exceptionally high in comparison with other varieties grown in the nursery. This was especially true in 1925, a year in which an excessive wet June was followed by a very dry July and August.

On the other hand, in 1926 and 1928, years in which spring moisture conditions were not favorable, the tillering in these selections was not noticeably greater than in other standard varieties, and their yields were comparatively low. That a tendency toward heavy tillering under favorable moisture conditions has been inherited from the emmer parent in these selections, however, seems quite apparent.

RESISTANCE TO INJURY BY WIND AND HAIL

As previously stated, all of the Yaroslav x Marquis selections that were continued after 1922 were descended from the strains that best withstood the ravages of a severe hail storm. Since 1922, the selection named Hope has repeatedly been observed to be remarkably resistant to both breaking down of the straw and shattering of the grain by wind and hail.

In several years, plats of Hope and Marquis have been left unharvested for the purpose of comparing the long standing qualities of the two varieties. In every case, the Hope variety has been found to stand much longer than the Marquis without shattering or breaking down. In several years the Hope plat has stood practically without damage until the midwinter thaws would soften the straw. Indications are that this selection has long standing qualities of a sufficient degree to be of great value from the standpoint of direct combining under the severe climatic conditions prevailing during the harvesting season in the northern spring wheat area.

RESISTANCE TO LOOSE SMUT

Complete freedom from loose smut has been observed in all of the Yaroslav x Marquis strains every year since the original selections were first grown in 1921. Several attempts to inoculate Hope wheat artificially with loose smut taken from Kota have met with negative results. In one experiment conducted in 1925 and 1926, a row of Hope wheat was grown between rows of Kota that carried a heavy infestation of loose smut in an effort to infect the Hope wheat. When the Hope seed was planted the following year, no smutted plants resulted although seed from the Kota rows again produced a high percentage of smutted plants.

From these observations and tests, it appears quite certain that Hope wheat is at least highly resistant, if not immune, to the form of loose smut commonly occurring in Kota wheat.

RESISTANCE TO BUNT

The resistance of the Yaroslav x Marquis selections to loose smut (*Ustilago tritici*) naturally raised the question of their reaction to bunt, or stinking smut (*Tilletia levis*). Several tests were conducted, therefore, to determine the reaction of Hope wheat to bunt. The first of these tests was run in 1925. Smut balls were collected from several varieties of locally grown wheat. These were mixed together and crushed, and the resulting spores used to coat the seeds of Hope and Ruby wheats. Twenty smutted seeds of each variety were planted, spacing the seeds 3 inches apart in rows 1 foot apart. No bunt developed in the Hope variety. However, the Ruby variety developed only two smutted plants. Consequently, the results were considered of little value, since Ruby wheat is known to be quite susceptible to bunt. The experiment was repeated in 1926, only this time Kota wheat was used as a check variety, and the smut used was collected from samples of Kota and Nodak durum. In this test, Kota developed 75% of smutted plants, whereas Hope remained entirely smut-free.

Smut tests were again run with Hope wheat in 1927 and 1928, but, with one exception, no smut developed in the Hope variety. The exception was in 1927 when a single smut ball developed near the base of one of the spikes in an off-type plant in the Hope row. This plant had the appearance of being a hybrid with some other wheat, and this may have accounted for its susceptibility. The smut ball was saved and an attempt was made to reinfect Hope wheat with spores from it the following year, but with negative results. It appears, therefore, that Hope wheat is at least highly resistant to certain forms of bunt. Concerning the origin and inheritance of this resistance to bunt, very little is yet known. The Yaroslav parent is peculiarly susceptible to bunt, but the Marquis parent is moderately resistant. The high degree of resistance in Hope appears to be the result of a recombination of the genetic factors of the two parents. While its origin is as yet undetermined, it appears to be an example of transgressive segregation. It seems reasonable to expect that the high degree of resistance of Hope wheat to bunt will be transmitted to certain of the offspring in crosses between it and other wheats.

EASILY LOOSENED BRAN

A peculiar characteristic of the Yaroslav x Marquis selections is the ease with which the bran may be removed from the kernel. When kernels of these selections are soaked in water for a few minutes, the bran is completely loosened and may be readily removed in one piece by the use of a pair of fine-pointed tweezers. In certain other wheats, notably Kota, a much longer period of exposure to moisture is required before the bran becomes loosened, and when loosening finally does occur, it does not appear to be complete, a fact which makes it difficult to remove the bran coat without breaking. This characteristic of these selections may be of some value from a milling standpoint in that it may make it possible to shorten the period required for tempering, thereby greatly speeding up the milling process It would also seem that this characteristic might make possible a sharper separation of the bran from the other products, thereby making for a larger run of the more valuable products, including the better grades of flour.

On the other hand, the easily loosened bran in these selections is somewhat objectionable from the standpoint of retaining a good appearance upon being exposed to wet weather in the field, especially while in the shock, since the loosening of the bran causes the grain to take on a bleached appearance. Furthermore, the loosening of the bran results in a lower test weight which is also considered objectionable from a commercial standpoint. Whether the easily loosened bran in these selections can be considered as a desirable or an undesirable characteristic is, therefore, a debatable question.

UNDESIRABLE CHARACTERISTICS OF YAROSLAV X MARQUIS SELECTIONS

All of the Yaroslav x Marquis selections have been found to have several undesirable characteristics in common. Among the more outstanding of these may be mentioned the following: (1) They are quite susceptible to three diseases, *viz.*, black chaff, anthracnose, and a form of root rot. (2) They appear to be somewhat lacking in capacity for high yields under favorable conditions, a characteristic that appears to be largely due to the shortness of the spikes and the fact that the spikelets seldom contain more than two kernels each. (3) The test weight usually runs somewhat lower than that of most wheats when grown under favorable conditions. The low test weight appears to be the result of the long, heavy brush and the long, slender kernel which has a tendency to taper toward the brush end. These kernel characteristics, taken together, make for an excessive amount of pore space, and naturally result in a low test weight. (4) They are easily bleached upon exposure to wet weather. (5) They are somewhat more susceptible to injury by spring frosts than most varieties of Hard Red Spring wheat. (6) They have a slight tendency toward uneven shrinkage of the endosperm upon ripening of the kernel. This sometimes results in wrinkled creases and flattened areas on the surface of the kernels. This defect is usually less pronounced in Hope wheat (H49-24) than in the other selections.

From general observations of numerous crosses between the Yaroslav x Marquis selections and other *vulgare* wheats, it appears quite certain that none of the undesirable characteristics mentioned above are inseparably linked with the desirable emmer characters.

SELECTIONS ARE TRUE *VULGARE* WHEATS

From general appearance, the Yaroslav x Marquis selections would be classed as true *vulgare* wheats of the Hard Red Spring class. Numerous crosses of H44-24 and Hope with other wheats of the *vulgare* group have been studied in the F_1 and following generations to determine if there was any tendency toward either sterility or malformity of the kernels of the hybrids as is the rule when wheats differing in chromosome numbers are crossed. No such tendency has been observed in any of these crosses. In fact, when crossed with awnletted *vulgare* wheats, there has been a decided tendency toward greater fertility of the flowers in the F_1 than in the awnletted parent. In crosses between H44-24 and Marquis studied in 1925, this increase in fertility of the flowers was especially noticeable toward the tips of the spikes, and appeared to be due to greater resistance to injury by drought and heat in the F_1 plants than in the Marquis parent. A single F_1 plant resulting from a cross between Hope wheat and Vernal emmer grown in 1924 produced a great number of sterile flowers, while all of the fertile flowers developed malformed kernels. These crossing experiments between the Yaroslav x Marquis selections and their parent species indicate that the selections contain the same number of chromosomes as the *vulgare* parent, and can, therefore, be classed as true *vulgare* wheats.

Since the writer had no facilities at his disposal for determining chromosome numbers by microscopic counts, it was decided to have someone else make these determinations. Accordingly, in the spring of 1925, seed of H44-24 was turned over to Dr. Fred Griffee of the University of Minnesota with the request that the chromosome number of this selection be determined by actual counts. Dr. Griffee's investigations, as reported to the writer, showed this selection to have the same number, 42, as other wheats of the *vulgare* group, a fact which should classify it definitely as a true *vulgare* wheat. There is no reason to believe that the other similar selections do not possess the same number of chromosomes.

DISCUSSION OF RESULTS

The emmer characters possessed by the common wheat segregates selected from the Yaroslav x Marquis cross demonstrate that it is possible to transfer desirable characters from wheats of the 28-chromosome group to wheats of the 42-chromosome group by means of crossing followed by rigid selection. In this project it appears that all of the desired characters of the 28-chromosome parent were not only successfully transferred to 42-chromosome wheats, but what is more striking, they were actually combined in a single 42-chromosome variety as the result of a single cross. That these characters were not inherited as a closely linked group seems probable since several of them have proved to be inherited independently in crosses of Hope and H44-24 with other *vulgare* wheats. These facts have considerable significance, since they appear to open up a new field of possibilities in wheat improvement. Here is good evidence that it is possible to breed into our common wheats desirable characteristics that are found at present only in widely different groups, such as emmer, durum wheat, einkorn, rye, *Aegilops* sp., and other related grasses. Furthermore, the occurrence of such characters as resistance to bunt and easily loosened bran in these selections demonstrates that characters of real value not apparent in either parent may be created as a result of the uniting of the genetic factors existing in the two parents. From these results it seems possible that a systematic breeding project involving the use of the various closely related wheat-like grasses might result not only in the successful transfer to our common wheats of many desirable characters, but also in the actual synthetic production of many entirely new characters, some of which might be of considerable economic importance. Although beset by many difficulties, the possibilities in this field are practically unlimited, and seem worthy of a thorough investigation.

GENETIC FACTOR RELATIONSHIPS IN THE B-Lg GROUP IN MAIZE[1]

H. E. Brewbaker and H. K. Hayes[2]

It is the object of this paper to present a picture of the B-Lg linkage group with evidence for the factor location of two easily workable characters, namely, glossy seedling, a recessive seedling character for which the factor symbol Gl_2gl_2 has been given; and flinty vs. floury *Fl fl*, an endosperm character for which two doses of either factor is dominant over one dose.

Linkage of the dominant plant color factor *B* with *lg*, a recessive factor for liguleless leaf and with ts_1 (originally designated *te*), the factor for pistillate-flowered tassel, was reported by Emerson (4).[3] Additional data on the *B-lg* relationship was given by Emerson and Hutchison (5) Demerec (3) reported linkage of the factor V_4 for virescent seedlings with the *B* and *lg* factors. Linkage of *sk*, a recessive factor for silkless ears, with *B* was reported by Jones (10). Anderson (1) reported backcross studies on the *B-sk* and *lg-sk* relationships.

In papers presented by Hayes and Brewbaker (7,8) data were given which indicated that gl_2, a glossy seedling factor, the factor pair *Fl fl* for flinty vs. floury endosperm, and *lg* were contained in the same chromosome group.

INDEPENDENCE OF THE B-Lg GROUP FROM OTHER GROUPS

An extensive test for linkage of gl_2 and *Fl* with factors in other linkage groups was made by Hayes and Brewbaker (7, 8), a summary of the data being presented in Table 1. Linkage intensities for 3:1 and 3:1 ratios were calculated by the product method as given by Fisher and Balmukand (6). Tables for facilitating the linkage computations and probable errors are available (9). Linkage values and probable errors for 3:1 and 1:1 ratios were computed by the product method from formulae by Immer (9). The recombination values are given in the following tables as decimal fractions.

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[1] Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Paper No. 981 of the Journal Series. Received for publication July 28, 1930.

[2] Formerly Assistant Plant Geneticist, Minnesota Experiment Station, now Associate Agronomist in Sugar Plant Investigations, U. S. Dept. of Agriculture, Fort Collins, Colo.; and Chief of the Division of Agronomy and Plant Genetics, Minnesota Experiment Station, respectively.

[3] Reference by number is to "Literature Cited," p. 1039.

Further evidence for the independence of *Fl* from factors in other linkage groups was obtained from backcross material at Cornell.[4] The summarized data are presented in Table 2. Probable errors were calculated as for Table 1.

TABLE 1.—*Recombination values of* gl_2 *and Fl with factors in other linkage groups than B-Lg,* F_2*, and backcross data, Minnesota.*

Genes		Linkage	Number of individuals					Recombination
Y	*X*	phase	*XY*	*Xy*	*xY*	*xy*	Total	value
Gl$_2$	C*	R F$_2$	2,530	875	1,892	678	5,975	.504±0.010
Gl$_2$	Wx	R F$_2$	1,646	573	533	174	2,926	.491±0.009
Gl$_2$	Sh	R F$_2$	1,281	439	374	114	2,208	.483±0.011
Gl$_2$	R	C F$_2$	3,718	1,316	1,496	509	7,039	.506±0.006
Gl$_2$	G	R F$_2$	610	184	168	60	1,022	.524±0.015
Gl$_2$	Su	R F$_2$	2,079	752	611	212	3,654	.494±0.008
Gl$_2$	Su	C F$_2$	1,598	594	448	165	2,805	.501±0.010
Gl$_2$	Tu	C Bc	138	113	122	93	466	.504±0.016
Gl$_2$	Y	R F$_2$	2,156	701	723	245	3,825	.506±0.008
Gl$_2$	Br	R F$_2$	974	292	255	92	1,613	.526±0.012
Gl$_2$	Ts$_2$	R F$_2$	917	278	304	98	1,597	.509±0.013
Gl$_2$	A*	R F$_2$	916	294	709	228	2,147	.500±0.011
Gl$_2$	Ra	R F$_2$	576	212	181	63	1,032	.492±0.016
Gl$_2$	Pr	R F$_2$	3,404	1,236	1,506	488	6,634	.484±0.006
C*	Fl	R F$_2$	784	654	775	571	2,784	.478±0.011
R	Fl	R Bc	979	967	1,014	956	3,916	.494±0.005
R	Fl	R F$_2$	2,041	792	1,952	651	5,436	.472±0.008
G	Fl	C F$_2$	1,153	336	1,082	301	2,872	.491±0.009
Y	Fl	C F$_2$	2,671	946	2,686	974	7,277	.504±0.002
Ts$_2$	Fl	R F$_2$	602	158	602	166	1,528	.509±0.015
Ra	Fl	C F$_2$	133	51	117	43	344	.492±0.029
Gl$_1$	Fl	R F$_2$	1,528	553	1,378	532	3,991	.512±0.009
Sl	Fl	R F$_2$	1,007	270	973	274	2,524	.509±0.012
Bn	Fl	C Bc	291	373	264	345	1,273	.500±0.010
Bm	Fl	R F$_2$	254	89	215	86	644	.525±0.023
Sg	Fl	R F$_2$	526	110	457	124	1,217	.549±0.015

*The *R* factor also segregating.

With but two exceptions, the deviation in recombination percentage from 0.500 is less than 3 times the probable error. One of these cases is found in the data for *Fl* vs. *R* in Table 1 where p = .472 ± .009, the deviation from 0.500 being 3.1 times the probable error. In the other case (Table 2), the recombination percentage for *Fl* vs. *R* is .429 ± .020, the deviation from 0.500 being 3.6 times the probable error. In both cases another cross gave results which definitely indicated independent inheritance of the factors involved. These studies indicate the factor *gl*$_2$ to be inherited independently of factors in all other groups, except *D*$_1$-*Pg*$_2$ where linkage studies have not been made. The factor *Fl* is apparently independent of all other groups.

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[4] The writers wish to make grateful acknowledgment to Dr. G. W. Beadle, Department of Plant Breeding, Cornell University, for the data included in Tables 2 and 3 of this paper.

TABLE 2.—*Recombination values of flinty floury vs. factors in known linkage groups other than B-Lg, backcross data, Cornell.*

Genes		Linkage	Number of individuals					Recombination
X	*Y*	phase	*XY*	*Xy*	*xY*	*xy*	Total	value
Fl	C	R Bc	65	63	55	60	243	.514±.022
Fl	R	C Bc	113	95	91	87	386	.482±.017
Fl	R	R Bc	68	91	74	56	289	.429±.020
Fl	G	C Bc	127	118	117	127	489	.481±.015
Fl	Tu	C Bc	139	123	100	118	480	.465±.015
Fl	Y	C Bc	334	269	288	273	1,164	.478±.010
Fl	PC	Bc	112	115	113	97	437	.522±.016
Fl	Bn	C Bc	152	145	143	173	613	.470±.014
Fl	A	R Bc	142	143	120	126	531	.505±.015
Fl	Pr	R Bc	134	138	119	97	488	.473±.015
Fl	Pr	C Bc	229	236	228	220	913	.508±.011
Fl	D$_1$	R Bc	91	97	100	69	357	.448±.018

LINKAGE WITHIN THE B-Lg GROUP

In a mimeographed preliminary report on a summary of linkage in maize prepared by Emerson, Fraser, and Beadle of Cornell University, the published data were summarized, together with certain unpublished results of linkage studies. The following linkages in the B-Lg group were obtained from backcross data which includes unpublished as well as published results.

Genes	Total number studied	Crossing over %
B lg	13,800	35.0
B ts$_1$	948	23.1
lg ts$_1$	537	40.4
B v$_4$	268	16.8
v$_4$ lg	1,800	43.2
B sk	2,917	7.2
lg sk	1,365	35.2

Linkage studies involving the factors *Fl* and *gl*$_2$ and other factors in the B-Lg group are summarized, the data being presented in

Tables 3 (Cornell) and 4 (Minnesota). The factors *Fl*, v_4, and *lg* were studied in a backcross involving a three-point relationship (Table 3). The flinty-floury separation was a rather difficult one in this cross.

The separation for flinty vs. floury in relation to normal vs. virescent seedlings is sometimes rather difficult. In such a study with a virescent obtained from Minnesota No. 13 dent corn there was considerable difficulty in making the separation and there was a definite correlation between floury seeds and virescent seedlings.

The relationship in a backcross test gave a calculated recombination value of .567 ± .012. There were too many floury virescent combinations and too few flinty virescents which is the opposite relation to that of the parents. This virescent seedling is known to be due to a factor which is genetically different from v_4, virescent seedling.

TABLE 3.—*Linkage relations of factors in the B-Lg linkage group, backcross data, Cornell.*

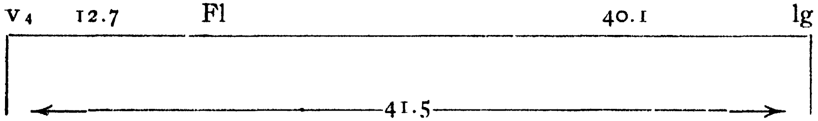
Genes *X*	Genes *Y*	Phase	*XY*	Linkage data *Xy*	Linkage data *xY*	*xy*	Total	Crossover value
Fl	B	C Bc	607	142	109	593	1,451	.173±0.009
Fl	B	C Bc	135	33	41	136	345	.214±0.018
Fl	B	Total	742	175	150	729	1,796	.181±0.008
							Average	.189
Fl	v_4	R Bc	78	452	430	50	1,010	.127±0.010
Fl	Lg	R Bc	210	320	285	195	1,010	.401±0.010
v_4	Lg	C Bc	292	216	203	299	1,010	.415±0.010

TABLE 4.—*Linkage relation of factors in the B-Lg linkage group, F_2 and backcross data, Minnesota.*

Genes *X*	Genes *Y*	Linkage phase	*XY*	Linkage data *Xy*	Linkage data *xY*	*xy*	Total	Crossover value
Fl	Gl_2	R F_2	387	209	497	93	1,186	.309±0.016
Fl	Gl_2	R F_2	299	177	346	52	874	.260±0.018
Fl	Gl_2	R F_2	85	43	109	23	260	.341±0.035
Fl	Gl_2	R F_2	357	163	421	81	1,022	.342±0.018
Fl	Gl_2	R Bc	175	388	426	139	1,128	.278±0.010
							Average	.306
Fl	Lg	R F_2	691	230	628	192	1,741	.484±0.014
Fl	Lg	R Bc	376	453	417	339	1,585	.451±0.008
							Average	.468
Gl_2	Lg	R F_2	536	279	290	6	1,111	.138±0.020
Gl_2	Lg	R Bc	163	697	678	175	1,713	.197±0.006
Fl	Ts_1	R F_2	232	159	404	10	805	.062±0.011
Gl_2	Ts_1	R F_2	519	195	230	26	970	.335±0.019
Gl_2	Ts_1	R F_2	672	240	220	22	1,154	.327±0.018
							Average	.331

The order for certain of the genes appears to be definitely as follows: *Fl*—*sk*—*B*—gl_2—*lg*. Crossover percentages for *Fl* with *B*, gl_2, and *lg* are 18.1, 31.6, and 48.3, respectively, while *sk* with *B* and *lg* gave crossover percentages of 7.2 and 35.2, respectively. There is some doubt regarding the relative positions of *Fl*, ts_1, and v_4 Data in relation to *B* gave crossover percentages of 18.9, 23.1, and 16.4, respectively, while gl_2 gave crossover percentages of 30.6 and 33.1 with *Fl* and ts_1. These data indicate that ts_1 is at the left of *Fl*. Crossover percentages of *lg* with ts_1 and *Fl* were 40.4 and 46.8. These indicate *Fl* to be at the left of ts_1.

The only satisfactory test for relative positions of closely linked factors is by the three-point test Such a study is available from Cornell data involving v_4, *Fl*, and *lg*. The difficulty of separating flinty vs. floury seeds in the presence of segregation for normal vs virescent seedlings has been emphasized The homozygous virescent condition tends to produce a floury endosperm The results obtained were as follows.



These results in themselves indicate that v_4 is at the left of *Fl*. Additional studies appear necessary before the order of the genes ts_1, *Fl*, and v_4 will be known.

SUMMARY

1 The factor gl_2, recessive for glossy seedlings, is shown to be independent of eight linkage groups and the factor pair, *Fl fl*, for flinty vs. floury endosperm, to be independent of nine groups.

2. The order of the genes in the B-Lg group appears to be (v_4—*Fl*—ts_1)?—*sk*—&—gl_2—*lg*). From the data at hand it is impossible to determine the relative position of v_4, *Fl*, and ts_1.

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BARLEY VARIETIES REGISTERED, III[1]

H. K. HAYES[2]

SPARTAN, REG. NO. 6

The original cross of Spartan barley was made and the early generations of breeding were conducted under the direction of the late F. A. Spragg at the Michigan Agricultural Experiment Station. It was tested and introduced by E. E. Down, H. M. Brown, and F. H. Clark, and Mr. Down applied for its registration. Spartan resulted from a cross of Michigan Black Barbless, a pedigreed line obtained from Lion, with Michigan Two-Row. The cross was made in 1916 and the last selection made in 1920.

The variety is two-rowed, classified as *Hordeum distichon palmella rigens*, and has the desirable characters of smooth, deciduous awn, stiff straw, and early maturity. It has been compared at East Lansing with Wisconsin Pedigree No. 9, the variety grown most commonly in Michigan, for 4 years, 1925 to 1928, inclusive.

Considering the yield of Spartan as 100, the yield of Wisconsin Pedigree No. 9 during the four years of the test has been 91.5, 91.9, 92.6, and 116.2, respectively. In 1929, in over-state trials, it was considerably superior to Wisconsin Pedigree No. 9 in yield. Its registration is justified on the basis of its smooth, deciduous awn, and its yielding ability.

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[1] Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 24, 1930.

[2] Chief of the Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minnesota; member of the 1929-30 Varietal Standardization and Registration Committee of the American Society of Agronomy charged with the registration of barley varieties.

REGISTRATION OF IMROVED WHEAT VARIETIES, V[1]

J. ALLEN CLARK[2]

Four earlier reports present the registration of 264 varieties of wheat. The first, in 1926, was the registration of 229 standard varieties. Since then, 35 improved varieties have been registered on the basis of performance. Certificates of registration have been issued for the improved varieties. In 1929[3], three varieties were registered and the previous articles cited.

Varieties approved for registration this year are as follows:

Varietal name	Registration No.
Ioturk	266
Iowin	267

The origin and performance of these varieties are given below.

IOTURK, REG. NO. 266

Ioturk (Iowa No. 1154), a selection from Turkey wheat, was produced by the Farm Crops Section of the Iowa Agricultural Experiment Station. The variety has been under experiment for 12 to 15 years at Ames and was distributed for commercial distribution about 1926. It has since replaced much of the other Turkey wheat in the state. Comparative yield data are shown in Table 1

IOWIN, REG. NO. 267

Iowin (Iowa No. 2025, C. I. No. 10017) was produced as a pure-line selection from Theiss wheat by the Farm Crops Section of the Iowa Agricultural Experiment Station. The variety has been included in plat experiments at Ames for 5 years, and 250 acres were grown to furnish seed for its first commercial distribution in the fall of 1930. Iowin is bearded and has white glabrous glumes, the stems are tall and fairly strong and the spikes somewhat open, and the kernels short, red, and semi-hard to hard. The advantages of Iowin are rust resistance and high yield. The yields from plat experiments, furnished by L. C. Burnett, the breeder and applicant, are given in Table 1.

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[1] Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 24, 1930.

[2] Senior Agronomist in Charge of Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; member of the 1929–30 Varietal Standardization and Registration Committee of the American Society of Agronomy charged with the registration of wheat varieties.

[3] CLARK, J. A., PARKER, J. H., and WALDRON, L. R. Registration of improved wheat varieties, IV. Jour. Amer. Soc. Agron., 21: 1172–1174. 1929.

TABLE 1.—*Comparative yield data of Ioturk and Iowin winter wheats in plats with other standard varieties at the Iowa Agricultural Experiment Station, Ames, Iowa, 1926–30.*

	Yield in bushels per acre					
Varieties	1926	1927	1928	1929	1930	Average
Iowin (new)	34.7	35.8	33.7	44.0	41.8	38.0
Ioturk (new)	31.8	23.5	38.7	44.0	45.4	36.7
Kanred (standard)	30.5	25.4	36.7	43.5	40.7	35.4
Minturki (standard)	27.0	21.0	42.7	41.8	44.2	35.3
Turkey (standard)	29.8	22.2	41.7	36.4	42.5	34.5
Iobred (standard)	26.1	22.8	38.6	38.4	39.0	33.0

Further information about Ioturk and Iowin wheats can be found in *Wallace's Farmer*, September 13, 1930.

BOOK REVIEW

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. London: Oliver & Boyd. Ed. 3. XIII + 283 pages, illus. 1930. 15/net.

The popularity of this unique work has resulted in the publication of a third edition. Dr. Fisher in his two previous editions brought to research workers a guide in statistical analysis that was sadly needed by those whose experiments could not be conducted with a large number of replications. Hitherto, these investigators were placed in a dilemma. If they presented their data without biometrical analysis, they were met with criticism by those biologists who looked with great favor upon this kind of interpretation, whereas, if the data were analyzed by the same methods the investigators were taken to task by the mathematicians for paucity of data. It is true that Student's methods and tables have been published for a considerable time, but the rank and file of biologists were not sufficiently grounded in statistical mathematics to make the widest use of the tables.

Dr. Fisher has elucidated these methods in his book. More than this, he has here brought together the results of his own extensive mathematical researches and by omitting proofs has produced a book that can be used by those biological investigators whose mathematics may not be advanced beyond the calculus and elementary probability. Perhaps Dr. Fisher's greatest contribution lies in his methods for improving experimental technic, both in the laboratory and in the field.

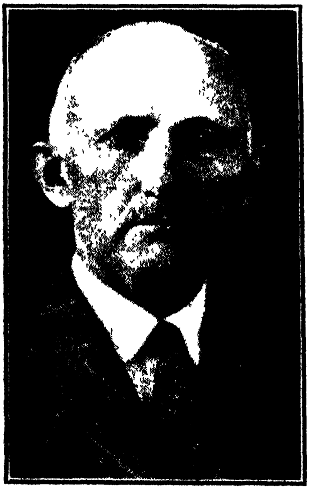
The third edition is similar to the second but contains important additions. One of these is the generalized form for the series of orthogonal polynomials which are useful in the fitting of curved regression lines. The other addition consists of two sections to the chapter on statistical estimation to illustrate further the applicability of the method of maximum likelihood. The first section deals with the statistical treatment of fragmentary data, a most valuable aid for certain experiments. The record shows how the amount of information can be evaluated and its precision determined with special reference to fragmentary data. (F. Z. H.)

FELLOWS ELECT

FRANKLIN S. HARRIS

Harris, Franklin S., Brigham Young University, Provo, Utah. Born at Benjamin, Utah, August 29, 1884. B.S., Brigham Young University, 1907; Ph.D., Cornell University, 1911. Instructor in science, Juarez Academy, Juarez, Mexico, 1904-05; assistant agricultural chemist, Brigham Young University, 1906-07; assistant chemist, Utah Experiment Station, 1907-08; assistant in soils, Cornell University, 1909-10; instructor, 1910-11; professor of agronomy, Utah Agricultural College and agronomist, Utah Experiment Station, 1911-21, director, 1916-21 Director, School of Agricultural Engineering, Utah College, 1912-16. President, Brigham Young University, 1921—. Chairman, section of agricultural engineering, International Dry Farming Congress, 1912-14. Member of A. A. A. S., American Society of Agronomy, Society of Agricultural Engineers, Farm Economics Association. Fellow of Utah Academy of Sciences Special interests, irrigation, dry farming, sugar beets, soils.

President Harris has long been a member of the Society and was its President in 1920. He has served on various committees, has participated frequently in the programs of the annual meetings, and has made many important contributions to agronomic knowledge.



JAMES A. BIZZELL

Bizzell, James A., New York State College of Agriculture, Ithaca, N. Y. Born at Glenwood, North Carolina, April 13, 1876. B.S., North Carolina College, 1895; M.S., 1900. Fellow, Cornell University, 1901-02, Ph.D., 1903. Instructor in chemistry, North Carolina College, and assistant chemist, North Carolina Experiment Station, 1895-1901. Assistant chemist, Cornell University Experiment Station, 1903-07; assistant professor soil technology, New York State College of Agriculture, 1907-12, professor, 1912—. Special interests, soil technology and fertility.

A charter member of the Society, Dr. Bizzell has always taken an active interest in its welfare, serving on numerous committees and in other ways advancing the cause of agronomic research.

WALTER P. KELLEY

KELLEY, WALTER P. University of California Citrus Experiment Station, Riverside , California. Born at Franklin, Kentucky, February 19, 1878. B. S., University of Kentucky, 1904; M. S., Purdue University, 1907; Ph.D., University of California, 1912. Assistant Chemist, Purdue University Experiment Station, 1905-08; Chemist, Hawaii Experiment Station, 1908-14; Professor of Agricultural Chemistry, University of California, 1914—. Member of A. A. A. S.; American Chemical Society; American Society of Agronomy; Western Society of Naturalists; International Society of Soil Science.

In addition to serving the Society as its President during the past year, Dr. Kelley has also served on many important committees and is now engaged in a survey of nitrogen researches in relation to soils and crops in this country and Europe to supplement the work of the Society's committee on the Chilean Nitrate of Soda Nitrogen Research Award.

AGRONOMIC AFFAIRS

MINUTES OF THE TWENTY-THIRD ANNUAL MEETING OF THE SOCIETY

The meeting was called to order by President W. P. Kelley at 9:30 A.M. on Thursday, Novermber 20, at the Hotel Raleigh, Washington, D. C. About 300 members and visitors were in attendance at the meetings.

The following special committees were appointed: *Nominating*—M. J. Funchess, C. F. Shaw, and M. F. Miller. *Auditing*—L. E. Call and Emil Truog. *Resolutions*—S. B. Haskell and J. D. Luckett.

The program which had been arranged was presented (page 1073).

The annual dinner was held at 6:30 P.M. at the Hotel Raleigh, 175 being present. President W. P. Kelley delivered the retiring presidential address (pages 977–985).

The annual business session was then held.

FELLOWS

The Fellows Elect were presented by Vice-President W. W. Burr (pages 1043–1044). The recipients of this honor were President F. S. Harris, Dr. J. A. Bizzell, and Dr. W. P. Kelley. Diplomas were presented

CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARDS

DR. S. A. Waksman, Chairman of the Committee on the Chilean Nitrate of Soda Nitrogen Research Award, before announcing the awards for 1930 called attention to point 5 of the plan of administering the annual nitrogen research award, *viz.*, that "the awards shall be made to individuals for outstanding nitrogen research in relation to economic crop production to be used in furthering nitrogen investigations or for professional advancement."

In all, 14 candidates were very carefully considered this year, by the committee, and the following three investigators unanimously selected to receive the award:

DR. JOSHUA J. SKINNER, a graduate of the University of North Carolina, now of the Bureau of Chemistry and Soils, U. S. Department of Agriculture, for his outstanding investigations dealing with the effect of different forms of nitrogen upon growth, yield, and quality of crop, and on the germination of seed; for his work on the effect of forms of nitrogen applied upon the percentage of soluble salts in the soil at the time of seeding, germination, and at the time of harvesting of annual crops; for his work on the effect of nitrogenous constituents on soil fertility. Dr. Skinner's work dates back to the important contributions of Dr. Schreiner and Dr. Shorey and their associates on the chemical nature of soil organic matter and especially upon the nitrogenous constituents of this organic matter.

DR. JAMES K. WILSON, a graduate of Oklahoma Agricultural College, assistant bacteriologist of the New York State Agricultural Experiment Station, associate plant physiologist at Cornell University, and now professor of soil technology at Cornell University, who has carried out outstanding work on the rôle of microorganisms in the transformation of nitrogen in the soil, including the influence of environmental conditions on nodule bacteria and their survival in the soil, influence of nitrates upon crop growth, and occurrence of ammonia-oxidizing organisms in the soil.

L. G. WILLIS, a graduate of Massachusetts Agricultural College, formerly assistant chemist of Pennsylvania Agricultural Experiment Station, and of the

Tennessee Experiment Station, Chemist of the Porto Rico Experiment Station, and now chemist of the North Carolina Experiment Station, for his work on the rôle of concentrated fertilizer materials upon plant growth, especially on the rôle of the different forms of nitrogen in these fertilizer materials; especially for his contribution in establishing the cause of the injury brought about by such fertilizers and pointing to its remedy.

Diplomas were presented and it was announced that the three men would share equally in the five thousand dollar award.

President Kelley then presented the following statement:

NITROGEN RESEARCH AND THE NITROGEN RESEARCH AWARD

It seems to me that the establishment of the Nitrogen Research Award has afforded the Agronomy Society a special opportunity whereby it can stimulate nitrogen research effectively, and that the consequence of this stimulation will be the substantial advancement of practical agriculture. Although the endowment of this award has been in force only three years, there are indications already of increasing interest in nitrogen research. My experiences as a member of the Award Committee have caused me to feel, however, that there is a lack of proper coordination of effort and the need for better organization in the work on nitrogen research.

The members of this Society were informed through a brief announcement in the Journal last spring of my having been commissioned to make a special study of the nitrogen researches in Europe and America with a view to the preparation of a report thereon. It was thought that such a report would be helpful to those engaged in nitrogen research. Because of this fact and its close relationship to the primary object of the Nitrogen Research Award, namely, the stimulation of nitrogen research, the Chilean Nitrate of Soda Educational Bureau of New York provided a special fund for the support of this survey.

Accordingly, I spent about three and a half months in Europe last summer. Unfortunately, the survey was interrupted prematurely owing to ill health on my part. However, the foundation was laid, I believe, for a report which will be useful to students of nitrogen research. Since the survey is only partially completed, obviously a final report can not now be made. However, some preliminary announcements seem to be in order at this time.

The nitrogen researches of Europe logically fall into two classes, namely,—(1) those having to do primarily with practical questions and (2) those which are chiefly theoretical and scientific. By far the larger amount of effort is being devoted to the practical type of investigation, which is probably accounted for in part by the agricultural depression that is quite general over Europe. Some extremely important lessons are emerging already from these investigations. One of these is that the amount, time, and method of application of nitrogen are chiefly local considerations dependent upon soil conditions, the crop that is being grown, the plane of general fertility and type of soil, and the character of farming into which it is being introduced. This means that a large number of local experiments must be made and that it is hardly likely that we will ever be able to answer the questions which the farmers so often propound without a large fund of local information.

The second point is that different commercial forms of nitrogen may produce widely different responses. It is, of course, well known that nitrates often give better results on acid soils than ammonium salts. It is not so well known that different nitrates may produce distinctly different effects. The underlying reason for these differences is in need of thoroughgoing investigation. A possible factor is that some one or more of the accessory constituents which are contained in certain of the commercial forms of nitrogen may play an important part in the final result, particularly on certain types of soil.

Only two types of theoretical research will be mentioned at this time. First, that relating to the function of nitrogen in plants, and the dependence of nitrogen nutrition on other elements. It is well known, of course, that nitrogen can not exert its greatest effect unless there is an adequate supply of available phosphate and potash. It is not so well known that potassium is apparently involved in the transformations which nitrogen itself undergoes in the plant, and that these transformations are of the greatest practical importance, especially in connection with the quality and storage of fruits. There is need for extensive researches along this line. Nitrogen is apparently intimately related to the quality of certain cereals, to fruiting, and other practical horticultural questions, but the best means of utilizing the underlying principles as well as of their satisfactory elucidation, are in need of thoroughgoing study.

The second theoretical point is in the field of microbiology. Some extremely interesting work is in progress along this line, but its volume is entirely inadequate. The results at Rothamsted have revealed that certain generally accepted ideas about nitrification are essentially erroneous, and evidence is not lacking that research along both practical and theoretical lines will throw important light upon other types of nitrogen transformation. I have special reference to nitrogen fixation by legumes, the possibility of the profitable application of soluble nitrogen to legumes, and the microbiological transformations of organic matter in soils in relation to nitrogen. I regret that time will not permit a fuller discussion of these and related matters.

Finally, it seems appropriate to point out that there is every reason why the Nitrogen Research Award should be administered in such way as to inspire the greatest confidence. There is, on the one hand, a real need for special endowments for research on agricultural subjects and, on the other hand, there is no good reason why the relationship between scientific institutions and commercial concerns should not be cordial. Nothing, in my opinion, will contribute more towards these ends than the conscientious and thoroughly disinterested administration of trusts that are already established.

Nitrogen fertilization is far from having attained unto its maximum possibilities both as regards its investigation and its practical utilization on the farm. In fact I am sure that both the American investigator and the American farmer have merely made a beginning. Extremely interesting developments await the intensive application of scientific research, and the practical value of the results is sure to be great. The generous financing of this work by the Chilean Nitrate of Soda Educational Bureau deserves the highest commendation. I am confident that the wise administration of this trust will materially advance both science and practice.

WINNING COUNTY AGENTS

Director F. J. Sievers, chairman of the judging committee, introduced the winners in the annual contest conducted by the National Fertilizer Association, for the best soil improvement programs submitted by county agents.

OFFICERS REPORTS

J. D. Luckett, Editor, presented the following report which, upon motion, was accepted.

REPORT OF THE EDITOR

Once more it is our privilege to render an accounting of our stewardship of the JOURNAL of the American Society of Agronomy, and we are pleased to state at the outset that we shall be able to present a somewhat more favorable picture of the publication situation than was possible at this time last year.

The year which is drawing to a close has been largely one of retrenchment in an effort to keep the publication schedule within the financial resources of the JOURNAL, and at the same time expedite the publication of contributions from members of the Society with the least possible delay.

It will be recalled that last year, upon our recommendation and with the approval of the Editorial Advisory Committee, the Executive Committee of the Society authorized certain modifications in the policies governing the JOURNAL. Among these changes was the discontinuance of the practice of publishing symposia as complete units in view of the congestion in the publication schedule which this practice occasioned. You will doubtless wish to know just what benefits, if any, have resulted from this change.

First, in our last report, we showed that the elapsed time between the acceptance of a paper, exclusive of symposia papers, and its appearance in the JOURNAL was approximately seven and a half months. We can now state that this time has been reduced to five months, with reasonable prospects for still further reduction without increased demands on the financial resources of the Society.

Second, and to our mind of considerable more importance, is that in spite of the fact that the current volume of the JOURNAL will fall more than 100 pages short of the 1929 volume and more than 300 pages below the record volume for 1928, there will appear in the 1930 volume more contributed articles, as distinguished from symposia papers, than in any previous volume of the JOURNAL, the number of contributed papers for 1928 being 102; for 1929, 73; and for 1930, 107. This was made possible, of course, by a very sharp decline in the number of symposia papers accepted for publication in 1930, only 9 such papers appearing in the current volume as compared with 41 in the preceding volume.

Once more we would make clear, as we attempted to do last year, that we entertain no prejudice against symposia papers as such and that all such papers submitted to us for publication in the JOURNAL will receive the same consideration as any other contribution. We are convinced, however, that the present method of handling these papers is working for the best interests of the Society in making its JOURNAL predominantly a record of new developments in agronomic research and for the best interests of contributors to the JOURNAL in affording a more equitable publication schedule.

It has been customary in the past to summarize the make-up of the current volume and in accord with that practice we wish to give herewith the figures for Volume 22. With the appearance of the December number, there will have been published in the current volume 107 contributed articles, 9 symposia papers, 15 book reviews, and 9 notes, together with numerous announcements and items of agronomic interest, occupying substantially more than a thousand pages. On November 1, we had on hand 13 papers that had been accepted for publication as contrasted with 33 at that time last year. Twenty papers have been returned during the year as unsuitable for publication for one reason or another, making a total of 173 articles, book reviews, and notes passing thru the Editor's hands prior to November 1, 1930.

To summarize briefly, then, we would say that with its present resources and in view of the experience of the past two years, the Society may look forward to the publication of about a thousand pages of material in the course of a year, and that by continuing the present policies with respect to the JOURNAL reasonably prompt publication may be expected.

An important factor in attaining this end is the continued effort on the part of all contributors to the JOURNAL to condense their material into as few pages of manuscript as possible. We are grateful for the very evident attempts to do this that come to our desk almost daily. However, we still find it necessary in some instances to ask for revision and shortening of manuscripts and at times must even reject papers that are obviously too cumbersome for our pages. This is not a pleasant procedure, either for us or for the author, and we would forestall it, if possible, by this word of caution.

We have received very material aid from members of the Editorial Advisory Committee and from others in helping us arrive at a judgment as to the disposition of several papers submitted to the JOURNAL in the course of the year which we are pleased to acknowledge herewith. We take this means also to thank those who have supplied us with news items regarding the personnel of their several departments and other matters of interest to agronomists generally, and would urge a continuation of their efforts in 1931.

Much credit is due the office of the Secretary for keeping the mailing list of the JOURNAL up to date and for rendering many other services too numerous to mention, for all of which we wish to make acknowledgment.

Finally, we should like to leave with you the thought that is constantly before us in handling the affairs of the JOURNAL; namely, that it is *your* JOURNAL and that it is our desire to make it as nearly what you would have it as lies within our power.

Respectively submitted,

J. D. LUCKETT, *Editor.*

REPORT OF THE TREASURER

The Treasurer submitted his annual report as follows, which was received and referred to the Auditing Committee:

I beg to submit herewith the report of the Treasurer for the year November 1, 1929, to November 1, 1930:

Balance, last report, general fund	$577.55
Balance, last report, Lime Assoc. fund	147.20
Total balance, last report	$724.75

RECEIPTS, 1930

Dues, 1930	$3,941.50
Dues, 1930 new	510.00
Dues, 1929	60.00
Dues, 1931	1,080.04
Subscriptions, 1930	1,620.78
Subscriptions, 1930 new	400.32

Receipts, 1930—*Continued*

Subscriptions, 1929	35.00	
Subscriptions, 1931	45.00	
Advertising Income	1,362.71	
Reprints sold	694.46	
Journals sold	196.00	
Index account	50.95	
	$9,996.76	$ 9,996.76
Total income, 1930		$10,721.51

Disbursements, 1930

Printing the Journal, reprints, etc. (13 issues, August 1929–August 1930 inclusive)	$7,570.95	
Engravings	130.74	
Salary, Business Mgr. (13 months)	812.50	
Postage (Sec'y and Bus. Mgr.)	104.33	
Printing (miscellaneous, programs, stationery, etc.)	165.00	
Express on journals	29.03	
Stenographic and mailing	182.75	
Miscellaneous (supplies, badges, expenses of annual meeting, refunds on accounts, etc.)	236.69	
Total disbursements	$9,231.99	$ 9,231.99
Balance on hand		$ 1,489.52

Balance, Lime Assoc. Fund	$ 147.20	
Balance, general fund	1,342.32	
Total balance		$ 1,489.52

Total income	$10,721.51	
Total disbursements	9,231.99	
Balance		$ 1,489.52

Respectfully submitted,
P. E. Brown, *Treasurer.*

Dean L. E. Call reported that the Auditing Committee had examined the books and vouchers of the Treasurer and found them correct. Upon motion the report was adopted.

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall reported as Assistant Treasurer in charge of the funds collected and disbursed in connection with the First International Congress of Soil Science. The report which follows was adopted:

American Society of Agronomy in Account with the Executive Committee of the First International Congress of Soil Science, Nov. 1, 1929, to Oct. 31, 1930

RECEIPTS

Sale of Proceedings of the First International Congress of Soil Science....	$ 426.92	
Sale of Abstracts	2.00	
Transportation on one set of Proceedings....	1.54	
Membership dues and initiation fees for International Society of Soil Science..	1,150.80*	
Interest on Savings Account (Prince Georges Bank and Trust Company, Hyattsville, Md.)....	44.43	
	$1,625.69	
Balance on hand November 1, 1929..	1,368.65	
		$ 2,994.34

EXPENDITURES

Office service..		$ 622.21	
Dues and initiation fees transmitted to Dr. Hissink.....		1,144.80*	
Postage....		80.00	
Stationery for office use...		13.80	
Premium on bond..		5.00	
Multigraphing 500 letters re dues and Second International Congress..		7.80	
Cablegram		3.20	
Rumford Press for mailing and distribution of Proceedings		127.90	
Guide Book to Soviet Russia		4.50	
Refunds on dues		6.00	
Refunds on Proceedings orders....		10.00	
Exchange on check..		.55	
Express charge		.52	
Difference due to error in last year's bank balance (See letters attached) Included under "Abstracts and Miscellaneous" Receipts in 1929 report.		30.00	
		$2,056.28	
Balance on hand in bank October 31, 1930.....	$959.06		
Less outstanding checks.....	21.00	938.06	$2,994.34

*Difference accounted for by refund of $6.00 because of overpayment of dues.

Submitted by
A. G. McCALL, *Exec. Secretary,*
American Organizing Committee.

Orders for Proceedings of the First International Congress of Soil Science distributed through office of A. G. McCall to and including October 1, 1930

PAID ORDERS

477 sets of Proceedings at $5.00 per set..............	$2,385.00
301 sets of Proceedings at $10.00 per set..............	3,010.00
	$5,395.00

UNPAID ORDERS

3 sets of Proceedings at $10.00 per set
228 Complimentary sets of Proceedings

1009 Total number sets of Proceedings distributed

ORDERED FROM RUMFORD PRESS

Sets of Proceedings of 4 volumes each		2,000
Copies of 5th volume	1,000	
Distributed as above		1,009
Remaining on hand in storage with Rumford Press at Concord, N. H		991
5th volume entirely exhausted		
Total number of Abstracts of the Proceedings distributed through this office		87

A. G. McCALL, *Exec. Secretary,*
American Organizing Committee.

REPORT OF THE SECRETARY

The report of the Secretary was read and upon motion was accepted as follows:

MEMBERSHIP CHANGES 1929–1930

Membership, last report			906
New members, 1930		99	
Reinstated members		20	
Total increase		119	
Dropped for non-payment of dues	53		
Resigned	24		
Died	5		
Total decrease		82	
Net increase			37
Membership, Nov. 1, 1930			943

SUBSCRIPTIONS

Subscriptions last report		454
New subscriptions	111	
Subscriptions dropped	40	
Net increase		71
Subscriptions, Nov. 1, 1930		525

MEMBERSHIPS AND SUBSCRIPTIONS BY STATES AND COUNTRIES

	Members	Subscriptions
Alabama	16	1
Arizona	9	1
Arkansas	4	3
California	29	7
Colorado	9	4
Connecticut	11	4
Delaware	5	2
District of Columbia	62	4
Florida	14	4
Georgia	19	3
Idaho	11	1
Illinois	43	15
Indiana	25	2
Iowa	33	6
Kansas	33	2
Kentucky	11	2
Louisiana	16	3
Maine	5	1
Maryland	12	3
Massachusetts	15	6
Michigan	22	3
Minnesota	21	5
Mississippi	7	4
Missouri	19	6
Montana	13	2
Nebraska	17	4
Nevada	1	2
New Hampshire	2	1
New Jersey	15	4
New Mexico	5	2
New York	46	25
North Carolina	15	2
North Dakota	16	1
Ohio	34	5
Oklahoma	16	4
Oregon	9	3
Pennsylvania	16	4
Rhode Island	4	0
South Carolina	10	1
South Dakota	8	1
Tennessee	7	2
Texas	42	5
Utah	12	6
Vermont	3	1
Virginia	20	2
Washington	11	4
West Virginia	8	1
Wisconsin	27	3
Wyoming	4	1
Alaska	3	1
Cuba	2	1
Hawaii	13	10
Philippine Islands	4	4
Porto Rico	3	3
Africa	9	27

	Members	Subscriptions
Argentina	7	9
Australia	5	25
Bolivia	1	0
Brazil	2	1
British Guiana	0	1
British West Indies	1	1
Canada	30	40
Ceylon	0	2
China	8	16
Czecho-Slovakia	0	1
Denmark	1	1
Dominican Republic	1	0
Dutch East Indies	0	2
Egypt	3	2
England	3	10
Estonia	0	1
Fed. Malay States	0	2
Fiji	0	1
Finland	0	2
France	0	6
Germany	5	8
Greece	1	0
Haiti	1	1
Holland	0	1
Honduras	2	1
India	3	12
Ireland	0	2
Italy	1	6
Japan	5	69
Jugoslavia	1	1
Latvia	0	2
Mauritius	0	1
Mesopotamia	1	1
Mexico	2	2
Northern Rhodesia	0	1
Norway	0	3
Peru	1	1
Poland	1	1
Portugal	0	1
Roumania	0	2
Salvador	0	1
Scotland	0	3
Serbia	0	1
Siam	0	1
Southern Rhodesia	0	1
South Wales	0	1
Spain	0	1
Sweden	2	4
Switzerland	1	0
Turkey	1	0
Uruguay	0	1
U.S.S.R. (Russia)	6	47
Wales	1	1
	943	525

MEMBERS BY YEARS

1908 Charter	34
1908	9
1909	5
1910	13
1911	22
1912	12
1913	15
1914	12
1915	20
1916	33
1917	16
1918	12
1919	15
1920	27
1921	47
1922	44
1923	30
1924	42
1925	81
1926	66
1927	76
1928	89
1929	124
1930	98
1931	1
Total	943

TOTAL MEMBERSHIP BY YEARS

1908	121	1916	586	1924	577
1909	129	1917	652	1925	646
1910	176	1918	509	1926	700
1911	236	1919	473	1927	767
1912	295	1920	436	1928	823
1913	349	1921	592	1929	906
1914	397	1922	643*	1930	943
1915	471	1923	561		

*In 1922 dues were increased to five dollars.

Respectfully submitted,
P. E. BROWN, *Secretary.*

HISTORIAN

Dr. T. L. Lyon, historian, made a brief progress report and asked for aid from the members in collecting information regarding the early history of the Society.

COMMITTEE REPORTS

COMMITTEE TO STUDY PLANS FOR THE REORGANIZATION OF THE SOCIETY

President Kelley reported the action of the Executive Committee in creating a special committee to study plans for the possible reorganization of the Society and to report at the next annual meeting. The Committee was announced as follows: M. F. Miller, *Chairman*, C. F. Marbut, C. R. Ball, S. A. Waksman, R. J. Garber, C. F. Shaw, T. A. Kiesselbach, Richard Bradfield, M. A. McCall, R. I. Throckmorton, O. S. Fisher, J. D. Luckett, *ex officio*, and P. E. Brown, *ex officio*.

EXECUTIVE COMMITTEE

The Secretary reported the following action of the Executive Committee: "Whereas a movement is on foot looking toward a reorganization of the American Society of Agronomy along broader and more liberal lines, the Executive Committee feels that the resolution referred to it by the special committee of the National Fertilizer Association in regard to the status of commercial members of the Society, should be held in abeyance pending recommendations from the special committee appointed to study plans for the reorganization of the Society, and action thereon next year. In the meantime the Executive Committee approves the interpretation of the Constitution, according to which the Secretary's office has been acting."

TERMINOLOGY

Dr. C. R. Ball, *Chairman*, presented the report of the Committee on Terminology, which upon motion was accepted, as follows:

During the year the recording of the current use of deprivative verbs having the prefix *de* has been continued In the two previous years, no less than 22 such verbs were found in current use. The list includes only those not specifically mentioned in recent editions of the Standard and Webster's dictionaries. It will be remembered that Webster's dictionary gives explicit warrant for the formation of such verbs as needed.

The list of 22 is as follows:

debitter
debunk
decode
de-egg
de-English
defat
defruit
deglume
dehull
dehusk
delead
delouse
deluster
demode
demouse
derate
deseed
desprout
desucker
detail
dethorn
dewool

During the current year, instances of the use of six of the above 22 have been noted again, in popular and technical literature. These six were debunk, dehull, delead, delouse, deluster, and desprout. In addition, the use of the verb delint, mentioned in the dictionaries, continues to be common in agronomic literature.

Since the last report of the committee, submitted one year ago, the use of seven hitherto unreported verbs of this class has been noted. This makes a total of 29 in all. These seven are:

decommission
defrost
dehair
denicotine
denitrate
deplane
dewater

Decommission was used by the Navy Department in designating ships to be eliminated from the navy.

Defrost was used in describing the raising of refrigeration temperatures to a point above freezing.

Dehair was used by a manufacturing company to describe the effect of a depilatory article.

Denicotine was used by a sales agency in advertising tobacco products from which the nicotine had been removed.

Denitrate was used in a standard work on the processes and products of the rayon industry.

Deplane was used by a writer in a current magazine as the aviation equivalent of the term detrain, used in military transportation.

Dewater, so far as observed, has been used only in the typewritten report of a committee dealing with irrigation problems, and may not yet occur in print.

As noted above, 29 such deprivative verbs have been recorded from current literature in the last three years. Some of them, like debunk, dehull, and deluster, as also the dictionary word, delint, have been used frequently. Others have occurred more rarely.

These words are simple in form and their meaning always is apparent at first glance. The introduction of several new ones each year, and the recurring use of those previously noted, would seem to indicate an unmistakable trend of the times toward brevity and clarity.

Charles F. Shaw,
Charles A. Shull,
Carleton R. Ball, *Chairman*

STANDARDIZATION OF FIELD EXPERIMENTS

Dr. R. J. Garber presented the report of the Committee on Standardization of Field Experiments, which was accepted as follows:

The committee gave consideration to the question of need for revision of the standards adopted by the Society at the annual meeting in November 1923, and published in the January 1924, issue of this Journal. It was concluded that it would be untimely to attempt extensive revisions at this time. Many important studies in field technic are now under way which will furnish additional valuable information. The data from these studies will doubtless be available in the near future and will be an important supplement to the data now at hand.

Attention is called to the need for experimental work along the following lines:

Varietal testing on soils of different productivity.—In view of the striking difference sometimes observed in the relative response of varieties of farm crops grown on soils of the same type but of different levels of productivity, it seems desirable that the Society should call attention to the need for more experimental data along this line. The difference in relative performance of varieties grown on soil types which differ sharply, have been recognized and generally have been taken into account in planning varietal experiments, but there does seem to be a need for more attention to determining the relative varietal response of crops grown on soils with different levels of productivity but which belong to the same general type.

Effect of time of planting with respect to varietal response.—Another phase of varietal experiments which has been generally overlooked is the possible influence of time of planting on relative performance of the varieties. This phase of experimental work deserves more attention by agronomists than it has received.

Because of the growing use of lysimeters in replacing field plats at some stations, it is considered desirable to supplement previously adopted standards with the following recommendations.

Methods in Lysimeter Experiments with the Pit and Tank Type

THE PIT

The pit, which is usually of reinforced concrete or blocks, must necessarily be built so that the floor is well below the ground level of the tanks. The top of the pit should not be much higher than the top of the tanks; otherwise it will influence the amount of rain which the tanks will receive. The floor of the pit should slope to an outlet, which may be a small cistern from which the surplus water can be pumped. A trough is advisable for the full length of the pit floor to receive the discarded water.

In the case of a hillside pit, drainage to a lower level obviates the construction of a cistern.

The usual pit will have only the top exposed, but a hillside structure will allow the exposure of one side and the ends as well as the top. The latter type admits of easier access, is more easily lighted and ventilated than the former, but the tanks can be placed on only one side.

A pit 82 feet long, 5½ feet wide, and 6½ feet high is ample for 116 1/10,000-acre tanks, the tanks being placed in a double row along both sides and at one end. This includes a 5-foot allowance at one end for a small table and storage space.

THE TANKS

Materials.—The tanks may be made of any one of a number of materials. Cracks are liable to come in concrete and disintegration of the exposed part takes place in any material that absorbs much moisture. Heavy galvanized iron is the cheapest and most readily workable material. No. 14 iron is advised. Some precautions are necessary in the case of this material. If crops are to be grown, the supply of lime in the soil must be sufficient to neutralize the zinc carbonate or other soluble salts of zinc which may be formed. Otherwise zinc poisoning of the plants may result. The liming required in field practice is sufficient.

A heavy coating of asphaltum is advised both outside the tank before set in place and inside before the soil is placed, but the inside coating will not insure permanently against zinc trouble, which would usually be expected in the course of three to five years.

The size of the tank is governed by the objects in view. If crops are to be grown, a tank 28.27 inches in diameter and which affords 1/10,000 acre of surface soil is highly satisfactory for small grains or other broadcast-sown crops. Larger tanks would be desirable for corn or sorghum. If no crops are to be grown the tanks can be much smaller—1/20,000 acre is a satisfactory size.

The top should be strengthened by an iron strap bradded to the rim. For a 1/10,000-acre tank a strap 1 inch wide and ¼ inch thick is satisfactory.

The depth of the tank is determined by the objects in view. If the study is limited to the changes taking place in the surface layer of soil the tanks should be shallow. For example, under humid conditions, 6 or 8 inches of soil might be desired. Allowing 4 inches of rim above the loose soil, the tank would be 12 inches deep. If the influence of the subsoil is to be studied the depth of tank should be increased accordingly, but only a 1-foot layer of subsoil underlying the 6-inch or other depth of surface soil is advisable in the case of a heavy soil.

It should be noted that common loam and clay loam subsoils retard to a marked extent the outgo. This applies even to nitric nitrogen. Three feet of clay loam subsoil may hold back nitrogen recovery for several years or even vitiate the results altogether. A sandy subsoil, on the other hand, may produce no appreciable effect of this kind, and hence can be several feet deep if desired.

The bottom of the tank.—The bottom of the tank should be constructed so that all free soil water will readily drain off. A cone-shaped bottom with outlet at the center and only a few inches lower than the tank wall is all that is required. A metal strainer is used to prevent stoppage of the outlet by soil. A bottom layer of quartz sand is essential to insure good drainage.

Outlet tubes.—The outlet tubes are usually made of block tin. Tubes with an external diameter of ⅝ inch and an internal diameter of approximately ½ inch have proved highly satisfactory. The outlet tube should be of sufficient length to allow a bend to make a water trap, which will limit the free circulation of air. (The trap is similar in shape to that commonly used for kitchen sinks.)

Placement of the tanks.—The tanks should be placed at least 2 feet from the outer wall of the pit. They should be set in the ground so that the soil, concrete, or other level outside the tank will approximately coincide with the soil level on the inside. The outlet tubes should pass through galvanized iron pipes which connect the tank with the pit. This will insure against breakage of the outlet tube and will facilitate tank replacement.

Soil placement.—The soil should be screened through a ¼-inch-mesh screen and thoroughly mixed prior to placement. It is important that the soil contain only enough moisture to be friable. In order to insure a uniform moisture content at time of weighing into the tanks, the soil should be kept covered during the preliminary operations. A temporary shed may be advisable, especially under conditions of heavy rainfall and when a large amount of soil is to be handled. Covers for the tanks are necessary in order to insure uniform moisture conditions at the outset and also for other control purposes.

The soil should always be placed in the tanks by weight. If large amounts of subsoil are to be used, it is best to put a given weight, representing not more than a 3-inch layer in the settled condition, into each tank in turn. To fill the tanks one at a time invites lack of uniformity in tamping, content of water-free soil, and composition both chemical and physical. The subsoil is compacted uniformly by light tamping after each successive 3-inch layer.

A soil sample should be taken from each tank at the time it is filled and placed immediately in a Mason jar for subsequent moisture and other determinations.

Containers for the leachings.—The containers for the leachings are of galvanized iron, asphalted on the inside, and are provided with removable and close-fitting covers. With a 50-inch rainfall, containers 16 inches in diameter and 18 inches high are of ample size for 1/10,000-acre tanks. When large containers are used a large-sized milk faucet facilitates the drawing off of the water into a tub for weighing and mixing before sampling.

The large containers are set on a shelf or bench, preferably at least 2 feet above the floor of the pit. The smaller containers for 1/20,000-acre tanks need not have faucets and are conveniently set on the floor of the pit.

The outlet tube from the tank passes through a cork set in a thimble near the edge of the cover.

Blank or check tanks.—The rain water should be collected in at least two blank or check tanks of the same size as the soil tanks and should be set up in the series. They need not have more than 6-inch walls, but should be provided with a funnel-shaped bottom like the soil tanks. A flat perforated disc fitting the funnel wall about half-way down will help to prevent the clogging of the outlet.

Preliminary leaching.—After the soil has been placed in the tanks a period of either artificial or preferably natural leaching should be allowed in order to remove excess of nitrates that can be expected to accumulate during the manipulation of the soil from the time of its removal from the field. A record should be kept of the amount of water received during this preliminary period and the amount and composition of the drainage should be determined periodically. The duration of the preliminary leaching is greatly influenced by the nature of the soil and the guidance of analytical data is required.

Fence.—The pit and tanks should be enclosed by a fence which will not permit small animals to gain entrance. The fence should not come near enough to the tanks to influence the rain or snow received by them.

Ground cover.—The ground about the tanks may well be covered with crushed rock or coarse gravel. Weeds and grass may be kept down by poisoning.

Additions to Bibliography Concerning Standardization of Field Experiments

Seventy-seven titles are appended for inclusion in the bibliography, as follows:

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This report, if adopted, together with previous reports published in January 1924, December 1924, and December 1926 contain all of the standards adopted by the society as well as the complete bibliography.

R. J. GARBER
H. H. LOVE
C. A. MOOERS
T. A. KIESSELBACH, *Chairman*

VARIETAL STANDARDIZATION

Dr. M. A. McCall, *Chairman*, presented the report of the Committee on Varietal Standardization which was accepted, as follows:

The committee has just completed its first year of service under the revised plan put into effect by the executive committee following the annual meeting at

Chicago in 1929. This plan involved the discontinuation of the special subcommittees charged with the registration of individual crops, and the centering of this function in the entire committee. In order to care for the registration of individual crops and to insure that each crop receives its proper attention, individual members of the committee have been made responsible for some one of the crops being registered by the Society. There is not unanimity of opinion among the committee membership as to the success of the present plan as compared with the previous plan of special subcommittees. Opinion of the present committee is practically equally divided in favor of the former and present plans.

During the year a plan for registering cotton varieties was prepared by Dr. H. B. Brown of the committee, in collaboration with a special committee appointed by the Agronomy Section of the Southern Agricultural Workers' Association. This plan was submitted to the members of the Varietal Standardization and Registration Committee for consideration. All of the members of the committee recognize that the cotton specialists are certainly more competent to determine the proper basis for the registration of cotton varieties, than anyone else. The plan prepared by Dr. Brown and his collaborators, however, departed to such an extent from other registration plans already approved by the Society, that it was deemed advisable to return this plan to Dr. Brown, together with certain suggestions of the committee members for consideration in turn by Dr. Brown and his collaborators. It is expected that a plan for the registration of cotton varieties will be submitted to the Society for approval at the next annual meeting.

The Society will doubtless be interested to know that the International Crop Improvement Association, by cross reference, adopted the rules of this Society for the registration of inbred lines of corn as an essential feature in their plan for the certification of hybrid seed corn.

During the year two varieties of wheat and one variety of barley have been registered. The registration numbers and descriptions, prepared by members of the committee, are presented elsewhere in the JOURNAL (pages 1040–1042).

Respectfully submitted,

J. H. PARKER
D. F. JONES
H. K. HAYES
E. F. GAINES
J. A. CLARK

F. D. RICHEY
H. B. BROWN
T. R. STANTON
M. A. MCCALL, *Chairman*

EDUCATION IN AGRONOMY

Prof. R. I. Throckmorton, *Chairman*, presented the report of the Committee on Education in Agronomy, which was accepted, as follows:

The committee on Education in Agronomy made a study during the year of the distribution of occupations of those men who have received bachelors, masters or doctors degrees in agronomy during the five-year period from 1926 to 1930 inclusive. The occupations listed are those during the late summer of 1930.

The study was made by means of questionnaires submitted to the Land Grant universities and colleges throughout the United States. Thirty-two institutions responded with the desired information. Of these, two stated that their undergraduate students do not specialize, and one institution was unable to supply information relative to present occupations of their graduates for the last five years. A total of 29 institutions reported on men who have received their bachelors degree, 29 on those who received their masters degree, and 10 on men who have received their doctors degree (Table 1).

TABLE 1.—*Distribution of occupations in 1930 of men who have received degrees in agronomy during the last five years, 1926–30.*

			Percentage of men who are									
Degree	No. of schools reporting	No. of men receiving degrees	Farming	Doing experimental work	Teaching in colleges and universities	Teaching in secondary schools	Teaching in high schools	In extension service	In commercial work relating to agriculture	In non-agricultural work	Doing graduate work	Not accounted for or deceased
Bachelor's.	29	661	19.1	15.1	2.6	1.5	15.3	12.3	13.3	6.7	10.7	3.5
Master's ..	29	255	0.8	44.7	19.2	3.9	2.7	5.5	7.5	3.1	9.0	3.5
Doctor's. .	10	116	0.9	51.7	28.5	0.9	0.0	3.5	5.2	1.7	0.0	7.8

Of the 661 men receiving their bachelors degree, 126, or 19.1% are farming; 100, or 15.1%, are engaged in experimental work; 19.4% are engaged in teaching in universities, colleges, secondary schools, and high schools; 12.3% are engaged in extension service; 13.3% are in commercial work relating to agriculture; 6.7% are in non-agricultural work; 10.7% are doing graduate work; and 3.5% are not accounted for or are deceased.

In 24 of the 29 schools, more than 10% of the men who have received their bachelor's degree during the last five years are farming. In 12 schools more than 20% are farming, and in three schools, Arizona, Connecticut, and New Hampshire, more than 30% are farming. In five of the schools, none of the graduates is engaged in farming.

In 21 schools, more than 10% of the men receiving their bachelors degree during the last five years are doing experimental work. In 11 schools, more than 20% are doing experimental work, and in four schools more than 30% are doing experimental work. In graduates from six schools there is no one doing experimental work at this time.

The 29 institutions reported a total of 255 men receiving their masters degree during the last five years. Only two of these men are farming while 114, or 44.7% are engaged in experimental work; 19.2% are teaching in universities and colleges; 5.5% are engaged in extension service; 7.5% in commercial work relating to agriculture; 3.1% in non-agricultural work; 9.0% are doing graduate work; and 3.5% of these men are not accounted for.

Considering the 255 men who have received their master of science degree, 72.9% are engaged in experimental work, college, or university teaching and graduate work.

The 10 institutions which reported on men who have received their doctor's degree showed a total of 116 men who received this degree during the last five years. Only 1 man in the group is engaged in farming; 60 men, or 51.7%, are doing experimental work; 28.5% are teaching in universities and colleges; 5.2% are in commercial work relating to agriculture; 1.7% are engaged in non-agricultural work, and 7.8%, or 9 men, are not accounted for

Of the 116 men who have received their doctors degrees during the last five years, 80.2% are engaged in experimental work and teaching in colleges and universities.

There are only 6.7%, 3.1%, and 1.7%, respectively, of the men having received their bachelor's, master's, and doctor's degree during the last five years that are engaged in non-agricultural work, while 15.1%, 44.7%, and 51.7%, respectively, are engaged in experimental work.

If the occupations being followed by our graduates of the last five years are any indication as to the future, our curricula in agronomy should be so planned that the men receiving their bachelors degrees would be well trained for farming, teaching of vocational agriculture, and for extension service and receive proper foundation for studies that will equip them for experimental work. This means that the curricula should be very flexible or should permit of a relatively wide range of electives. The work leading towards the master's degree should be so planned as to provide the best possible training for experimental work and for teaching in colleges and universities. The same requirements of course hold true for work leading towards the doctor's degree.

TABLE 2.—*The five state institutions which have had the highest number of men receive their bachelor's, master's, and doctor's degrees in agronomy during the last five years, 1926–30.*

Bachelor's		Master's		Doctor's	
State	Number	State	Number	State	Number
Michigan	80	Iowa	37	New York	51
Kansas	64	Kansas	23	Iowa	18
Nebraska	58	Nebraska	22	Minnesota	13
Iowa	57	Michigan	19	Wisconsin	13
South Carolina	53	New York	19	New Jersey	7
Total for the 5 states	312		120		102
Percentage of the total for all states reporting	47.2		47.1		87.9

A high percentage of the men receiving their bachelor's, master's, and doctor's degrees come from a relatively small number of institutions as is shown by Table 2. Five institutions have graduated 47.2% of the men who have received their bachelor's degree; five have granted 47.1% of the master's degrees; and five have granted 87.9% of the doctor's degrees.

H. O. BUCKMAN
J. O. MORGAN
O. W. DYNES
HENRY DORSEY
I. R. THROCKMORTON, *Chairman.*

FERTILIZERS

Dr. A. B. Beaumont, *Chairman*, presented the report of the Committee on Fertilizers which was accepted, as follows:

The Committee on Fertilizers has been concerned primarily with two projects during the past year. First, it has continued its activities with reference to the digest of literature bearing on the effect of fertilizers on quality of crops. The preliminary report on this subject was distributed in mimeographed form last March by the National Fertilizer Association to members of this Society and of the National Fertilizer Association. It was hoped that a goodly percentage of those who received the report would aid the committee by sending constructive criticisms or comments. Only a few replies have been received. We wish to urge those who have not responded to do so at an early date so that the reviewer may have the benefit of their knowledge or opinion.

The preliminary study brought out the fact that a thorough study of both American and foreign literature would require more time than the members of the committee could give. In order to make further and adequate study possible, the National Fertilizer Association last June appropriated $2000 for the purpose, $1500 of which is to be used on the digest and bibliography and $500 for publication of the final summary. The offer has been accepted by the Executive Committee. Negotiations were opened to secure someone not actively identified with the fertilizer industry to do the work. We are pleased to report that Dr. Burt L. Hartwell, formerly director of the Rhode Island Experiment Station, has been employed. It is hoped that a final report on the project will be ready a year hence.

Second, your committee has concerned itself further with the problem of fertilizer ratios. In its report of two years ago this committee affirmed its belief that the 36 3-component and 27 2-component ratios of the decimal triangle were sufficient to meet the demands of both producer and consumer. Logically, the next step is to determine the requirements of specific crops and soil conditions. Agronomists are constantly pressed by consumers of mixed fertilizers on the one hand and producers on the other, for advice as to the proper fertilizer mixture for certain crops and conditions. It is merely a matter of words as to whether one speaks of the fertilizer ratio, nutrient requirements or plant-food balance, the problem is the same and a very important one. So long as farmers use mixed fertilizers the problem will exist, and agronomists cannot successfully side-step it no matter how difficult its solution. For these reasons we began this year a study of the great mass of literature published in this country on the question of fertilizers for certain crops. The three important field crops, corn (maize), cotton and hay, have been chosen for immediate consideration. Out of this study it is hoped will come a better acquaintance with existing knowledge, a clearer conception of the limitations and possibilities of methods which have been used, and a constructive program for future research. This, of course, is a big undertaking, and little more than progress can be reported at this time. Preliminary literature studies made by members of the committee show a highly chaotic state of knowledge of the subject, out of which it is difficult if not impossible to bring a semblance of order.

A third matter which this committee wishes to bring to the attention of the Society is that of the need for an additional channel for publication. The membership of the Society has reached the point where it includes a great diversity of interests. The demands for space in the JOURNAL have grown apace. There is a feeling among some of the members of the Society that we have reached a point in our development as a society, such as was reached by the American Chemical Society years ago, where it would be advantageous to differentiate the published papers according to subject matter. Another journal published by the Society would make this possible, and relieve the present congestion of our JOURNAL. This committee has gone on record as favoring such a departure in policy and wishes to reaffirm its belief in the wisdom of such a move. The name Journal of Fertilizer Science was suggested, but it might well be Journal of Plant Nutrition or anything else carrying the same idea.

M. F. MILLER F. E. BEAR
H. J. HARPER A. B. BEAUMONT, *Chairman.*

FERTILIZER DISTRIBUTING MACHINERY

Prof. Emil Truog, *Chairman*, presented the report of the Committee on Fertilizer Distributing Machinery, which was accepted, as follows:

The Committee on Fertilizer Distributing Machinery of the American Society of Agronomy, working in cooperation with the Joint Committee, is pleased to report that its sphere of influence has been greatly expanded and extended during the past year. A complete report of the year's work resulting from the influence and stimulation of the Committee would fill at least one good sized volume. Your Committee's report, at this time, is of necessity very brief, and, simply calls attention to a few outstanding developments of the past year, which are as follows:

1. The work of a year ago in testing different types of machines for applying fertilizer to cotton was supplemented this past year by machine placement studies carried on by the Bureau of Public Roads, the Bureau of Chemistry and Soils, the South Carolina Experiment Station, and the National Fertilizer Association, working in cooperation. Differences in crop results due to placement of fertilizer often exceed those secured from differences in ratios and amounts of plant foods. It is clearly apparent that the texture of the soil, and probably climate, influence the relative effectiveness of different placements. The Committee is glad to report that with the increased financial support now available, this work with cotton will be expanded in scope next year.

2. In the case of the corn test, the Committee is highly gratified in the general cooperation which has been given by the agronomists of so many of the experiment stations. To effect this cooperation has meant just so much more work on the part of the station agronomists because of the fact that special funds are not available for this work. Twenty-three stations cooperated in the corn test during the past year, some conducting the experiment on more than one field. Although adverse weather conditions and other factors interfered with the experiment in a number of cases, unusually valuable and enlightening data have been secured by a majority of the cooperators. In general, hill fertilization has again been far superior to broadcast fertilization. The results of this work are being tabulated and digested, and will be made available to all of the cooperating stations and interested parties. The desirability of conducting an experiment of this kind at many points over a wide territory, in order that a considerable range of climate and soil conditions may be encountered is strongly emphasized by the results of the past season. As far as the Committee knows, this is the first time that a fertilizer test of this kind has been carried out in exactly the same manner over so wide a territory.

3. Manufacturers of fertilizer distributing machinery, in increasing number, are becoming actively interested in the fertilizer placement experiments. Much new development work, directed toward the improvements of present devices is already under way. In this, the manufacturers are redesigning their machines to give placements approximating those that seem preferable on the basis of recently secured information. Moreover, there is an increasing tendency on the part of manufacturers to utilize the services of the Committee and of the cooperating research agencies in testing out the efficacy of new machines prior to their commercial development.

4. In conclusion it seems desirable to point out that the work done to date brings into question the soundness of some of the past and present agronomic teaching on the placement of fertilizers, and the sufficiency of the research evidence on which it is based. Most striking are the facts revealed by the corn experiments of 1930, which show hill fertilization to be vastly superior to broadcast fertilization. An extreme case along this line is found in the data presented by the Minnesota Station. In this instance, 500 pounds per acre of 4-10-6 ferti-

lizer applied broadcast produced no increase in yield, while 125 pounds per acre of the same fertilizer applied in the hill increased the yield more than 25 bushels per acre. Therefore, we raise the question—should not many existing fertilizer experiments be modified so as to include the application of fertilizers in accordance with the new knowledge on fertilizer placement?

5. It is recommended that a committee be again appointed for next year.

J. R. FAIN S. B. HASKILL
R. M. SALTER EMIL TRUOG, *Chairman.*

SPECIAL JOINT COMMITTEE WITH THE INTERNATIONAL CROP IMPROVEMENT ASSOCIATION

The Secretary read the report of this committee, which was accepted.

TERMINOLOGY OF SEED OF IMPROVED VARIETIES

The Committee on Terminology of Seed of Improved Varieties has made a further careful study of terms and definitions of the same during the past year and while we are agreed that further terms are essential and necessary in a well-rounded out terminology for seed of improved varieties we are not ready at this time to make recommendations.

A meeting with the joint committee representing the International Crop Improvement Association was not arranged though an exchange of ideas was effected by correspondence through the committee chairmen.

The Committee recommend that this brief report be accepted and that the work of the committee be continued.

F. A. BUSSELL P. C. MANGELSDORF
R. A MOORE WALDO KIDDER
G. H. CUTLER, *Chairman.*

EUROPEAN CORN BORER INVESTIGATIONS

Dean L. E. Call, *Chairman*, presented the report of the Joint Committee on Corn Borer Investigations which was accepted, as follows:

The natural spread and increase of the European corn borer which might be anticipated in a normal season did not materialize in 1930 An abnormally small spread to new territory has occurred this season and in general there has been a decrease in borer population in the older infested regions of the one-brood area, although in Indiana and New York an appreciable increase. This situation has resulted from decidedly abnormal weather conditions, beginning when the moths first emerged, which checked flight and egg-laying. Later, seasonal conditions were responsible for a marked decrease below normal larval survival. In spite of the temporary check which has operated against the corn borer, there are a larger number of corn fields carrying a more uniform residual infestation, which forecasts a potentially serious increase and spread in 1931 if weather conditions are favorable.

The present infested area includes all of the corn-growing areas in Canada, excepting the western provinces; also 215,000 square miles in the United States, including the southern two-thirds of New England, northern extremity of New Jersey, all of New York, three-fourths of Pennsylvania, the panhandle of West Virginia, practically all of Ohio, northeastern third of Indiana and nearly all of the agricultural portion of Michigan. In the area east of the Connecticut River in Connecticut, Massachusetts and states north, and that territory in Connecticut west of the river adjacent to Long Island Sound the two-brooded form occurs, while in all other sections of the United States and all infested areas in Canada, excepting Nova Scotia and New Brunswick, only the one-brooded form occurs.

The fact that there has not been a normal increase and spread the past season emphasizes that we may anticipate seasons of increase and decrease in borer abundance as is true of other crop pests and that a temporary check such as the corn borer received in 1930 does not minimize the potential seriousness of this insect as a destructive agency. The Joint Committee, therefore, reiterates a statement made in its report a year ago, as follows:

"It, therefore, is still the opinion of the Joint Committee that, unless the corn borer is controlled, it will become one of the most destructive crop pests ever introduced into America. The situation, presenting as it does, the possibility of enormous agricultural losses, calls for the continued cooperation of the farmer, the scientist, the educator, and all State and Federal administrative officials."

The committee of entomologists, agronomists, agricultural engineers, agricultural economists, and animal husbandmen commends the efforts of all farmers practicing recommended control measures and those engaged in the research, regulatory, and educational activities.

The committee recognizes the necessity for the continued development of the research, educational, and quarantine programs of the State and Federal Governments and earnestly recommends the appropriation of the funds needed to maintain and, if necessary, to expand them as suggested later in this report.

After careful investigation of the regulatory, research, and educational activities, the committee suggests and recommends:

1. Since the enforcement of quarantine regulations in the United States has undoubtedly been instrumental in preventing long distance spread of the insect in the past, that this activity of the Federal Governments of the United States and Canada, as well as the State and Provincial governments, be supported and encouraged by all agencies and individuals interested in the welfare of American Agriculture. These activities should include, (a) thorough scouting, (b) careful clean-up of isolated infested areas, and (c) maintenance of quarantines.
2. That the extension agencies of the Federal governments of the United States and Canada and of the State and Provincial agricultural colleges, strengthen and coordinate their programs of education relating to the corn borer, extending these to conform with the spread and abundance of the insect and with the increased knowledge gained through research.
3. The entomological investigations now in progress should be continued and the following studies should be stressed because of their particular importance; (a) the expedition of parasite introductions and the development of artificial media for mass production of parasites, (b) the development of effective insecticides and their efficient application, (c) evaluation of the effect of environmental factors on the insect's activity.
4. While the development of *immune* varieties seems unlikely at this time, experiments point clearly to the probable development by breeding of high yielding *resistant* and *tolerant* varieties of corn which should be an important factor in control. To promote the development of such varieties, the corn breeding programs of the State and Federal governments should be continued and strengthened.
5. It is recommended that research with farm implements be continued by the individual state experiment stations as well as by the Federal departments of agriculture, and that such research be well supported. Investigations should include the further development of plows and plow attachments and attachments which can be applied to equipment already on the farm; also a further study of pickers with stalk handling attachments, rakes and other stalk handling equipment. The valuable assistance and cooperation given by manufacturers of farm equipment is highly commended.

6. Since the corn borer control practices developed and proposed may change the organization and income of the farm it is important that the relation of these practices to the entire farm business be determined and recommendations made for specific conditions. Proposals including changes in cropping systems, complete utilization of corn, substitute crops, changes in corn acreages, and labor and equipment costs should be worked out in line with the objective of maximum returns from farming.

7. Continued and further studies should be made on the influence of different degrees of corn-borer abundance upon; (a) feeding value of corn and the corn plant in different forms, (b) upon the yield of feed nutrients per acre, (c) comparative feeding value due to different methods of harvesting and preparing crop, (d) use and feeding value of substitute crops and (e) the influence of the corn borer and resultant control measures upon the cost of production and the quality of livestock products.

American Association of Economic Entomologists:
G. A. Dean   D. J. Caffrey
L. Caesar   T. J. Headlee
J. J. Davis

American Society of Agronomy:
L. E. Call   J. F. Cox
W. L. Burlison   R. M. Salter
F. D. Richey

American Society of Agricultural Engineers:
C. O. Reed   A. L. Young
T. W. Paul   R. B. Gray
R D. Bardon

American Farm Economic Association:
E. D. Hill   J. Coke
C. R. Arnold   Lynn Robertson
C. L. Holmes   R. R. Hudelson

American Society of Animal Production:
E. W. Sheets   Paul Gerlaugh
F. G. King   G. A. Brown
F. B. Morrison

REPORT OF THE REPRESENTATIVE ON THE NATIONAL RESEARCH COUNCIL

Dr. C. R. Ball, representative of the Society in the Division of Biology and Agriculture of the National Research Council, reported on matters of interest to the Society. The report was accepted, as follows:

The chief activity of the Division of Biology and Agriculture which has interest for the American Society of Agronomy is that relating to the work of the Committee on the Effects of Radiation upon Living Organisms. Its Sub-committee on the Allotment of Grants has appropriated for the year 1930–31, the sum of $22,850, including reappropriations, to 23 investigators (or groups). Besides this, additional apparatus has been secured for investigators through loans or by gift, either to the National Research Council or direct to investigators.

The Committee also has established a sub-committee to make a survey of the research in this field and to make recommendations regarding the most profitable lines of attack upon the problems of radiation in its biological aspects. This sub-committee has worked out a plan for the organization of seven advisory groups, one for each special division of the field.

Among the papers appearing during the year which result from the activities of this Committee are two by T. H. Goodspeed, dealing with tobacco and printed in the University of California Publications: Botany, and one by L. J. Stadler, dealing with Avena and Triticum, and published in the Proceedings of the National Academy of Sciences for 1929. It is interesting that the two workers in this field mentioned by Dr. W. C. Curtis, Chairman of the Division, in his paper before the Experiment Station Sub-Section of the Land-Grant College Association, were Dr. Stadler of Missouri and Dr Randolph of New York, both presumably members of this Society, and both working on corn in cooperation with the U. S. Department of Agriculture.

CARLETON R. BALL, *Representative*.

BIOLOGICAL ABSTRACTS

The Secretary called attention to the report received from Dr. J. R. Schramm in regard to Biological Abstracts and upon motion the report was accepted and ordered printed with the minutes of the annual meeting, as follows:

Dr. C. E. McClung, President of the Union of American Biological Societies, informs me that it will not be practicable to hold a meeting of the Council of the Union at the Des Moines meeting. Since Biological Abstracts is a creature of our national biological societies, he therefore suggests that I submit a brief report to the Society representatives on the Council to be brought to the attention of their respective societies as opportunity may present itself at the coming meetings.

The year has been one of substantial progress. Thirty-six thousand abstracts have been published in 1929 (45,000 sent to press), and with the January, 1930, issue the regular monthly publication schedule of single numbers will have been established, the numbers containing on the average about 3,000 abstracts each. The arrears in publication have been greatly reduced during the year; some still remain but it is expected that during 1930 these will be practically eliminated.

It was hoped that the indexes of Volume 1 would be issued before the meetings, but this has not been possible. The indexes provide both a systematic topical and alphabetic subject approach to the literature, and as such will, it is believed, prove unusually serviceable. Their initial organization, however, is a difficult and time-consuming task. The editors are adhering steadily to the policy of setting reasonably high standards and working out sound policies and procedure, knowing that in so doing speed of issuing subsequent indexes will be greatly increased and the quality safeguarded. The systematic index, which has been difficult because it involves adoption by the section editors of systems of classification of the groups throughout the organic kingdom, is practically all in type and partly proof read. The subject index with its innumerable problems is partly in type and will be wholly so within the next two months. The indexes of Volume 1 may therefore be expected *confidently in the Spring*.

The seriousness of the delay in the indexes is appreciated. It is hoped however that biologists will approve the policy of proceeding sufficiently deliberately to establish sound policies and standards in the initial effort. It should again be pointed out that the permanent reference value of an abstracting journal depends almost wholly upon the quality and completeness of its indexes

Aside from progress in publication the most significant development of the year is the cooperation from the Federal Department of Agriculture, which made possible on July 1 last the establishment of a branch office in the Department of Agriculture Library at Washington. All incoming library material is seen by the Biological Abstracts staff and all journals with suitable biological content not already perused at Philadelphia or elsewhere are covered. As there is no

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LIBRARY, NEW DELHI-110012

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